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The Relation of Forest Composition and Rate of Growth to Certain Soil Characters

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Connecticut
Agricultural Experiment Station
New Haven

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FOREWORD

The last decade has seen a renewed interest in the problems of land utilization, particularly in the northeastern quarter of the United States. The "abandoned farm" and the losses in rural population have been subjects of frequent discussion by economists, sociologists, foresters, agriculturalists and the public in general. Plans without end for repopulating the countryside have been brought forward. All are seeking the same end, the wisest use of our land resources for agriculture, forestry and recreation. We find ourselves involved in large forest planting projects, the purchase of land for public parks and forests, the setting up of game preserves, and in some cases, the exploitation of large areas for agricultural purposes. A sound policy must be based on a knowledge of our soils and their adaptation to crops and forests; on the number and character of our people and their standards; on our social institutions; and on the economic forces and trends that will inevitably influence our actions.

Under the present economic conditions a considerable portion of the land area of Connecticut is potential forest land. It is safe to assume that this will be true always. Therefore the wise use of forest land is one of our outstanding problems. Good policies must be based on a knowledge of the underlying facts and these facts are often woefully lacking. In 1923, the Station began an intensive study of the soils of Connecticut (see Bulletin 320), with the hope of furnishing a sound basis for our future land policy. The soil is an important forest site factor, although, strangely enough, it often has been overlooked. The problem is a broad one and of necessity must be attacked in detail. The studies here reported deal with certain phases of the relationship of forests to soils.

The investigation was undertaken jointly by the Soils and Forestry Departments of the Connecticut Agricultural Experiment Station, under the direct supervision of M. F. Morgan, Agronomist, and H. W. Hicock, Assistant Forester.

The writers are indebted to the following persons for assistance in the field and laboratory and in the preparation of this report: S. N. Spring, professor of silviculture, Cornell University; Barrington Moore, editor of *Ecology;* Dr. G. W. Conrey, chief of soil survey, Ohio Agricultural Experiment Station, Columbus; A. F. Hawes, Connecticut state forester; H. G. M. Jacobson, D. B. Downs, and W. O. Filley, of the Connecticut Agricultural Experiment Station, and George D. Scarseth, formerly of the Connecticut Agricultural Experiment Station.

CONTENTS

PART I

A STUDY OF SOIL TYPE AS A FACTOR IN DETERMINING THE COMPOSITION OF NATURAL, UNMANAGED MIXED HARDWOOD STANDS

Work was begun in the spring of 1926 and continued through 1927 with the immediate objective of investigating the influence of soil type, as recognized and mapped according to the Bureau of Soils classification, on the distribution and growth of forest vegetation. The project was outlined in this way because the Soils Department for several years had conducted similar studies on agricultural land in various sections of the state and was, therefore, well prepared to make the necessary soil type maps.

GENERAL DESCRIPTION OF EXPERIMENTAL TRACTS

The factors governing the choice of tracts were:

1. That they be fairly representative of the forested conditions found in Connecticut.
2. That the stand be reasonably uniform as to age and density.
3. That satisfactory soil and cover conditions be present over fairly large areas (50 acres or more).
4. That several of the more important soil types be well represented.
5. That they be readily accessible.

As might be expected, it was impossible to find areas that satisfied all these requirements. However, those chosen were probably as satisfactory as could be obtained. In order that the work might proceed unhampered and the experiments continued over a considerable period if necessary, it was decided to carry out the investigation on state forest land. Suitable locations for the proposed work were found on the Cockaponset State Forest, situated in the towns of Haddam, Killingworth and Chester (Middlesex County), and on the Meshomasic State Forest, situated in the towns of Portland, East Hampton, Marlboro, and Glastonbury (Middlesex and Hartford Counties). (See Figure 49.)

To determine the general conditions prevailing, the Soils Department made a soil and cover survey of these two forests together with considerable adjoining territory in 1926 and 1927. On the basis of this survey the Turkey Hill Experimental Tract was laid out on the Cockaponset State Forest in 1926. The fol-

lowing year the Cabin, Cox and Reeves Experimental Tracts were laid out on the Meshomasic State Forest. Although these two forests are some 20 miles apart, general conditions of stand, topography and soils are quite similar.

All of these tracts are near the western end of the Eastern Highlands, a region of metamorphic rocks and glaciated soils. The topography is gently rolling to rugged with considerable rock outcrop. In the general localities where the work was performed the

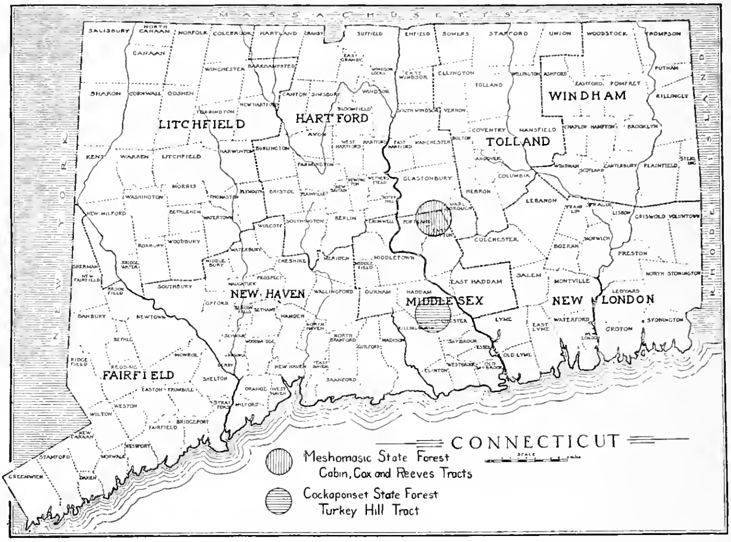

FIGURE 49. Map of Connecticut showing the general location of the Cockaponset and Meshomasic State Forests.

maximum differences in elevation do not exceed 400 feet, the absolute elevations ranging from 400 to 800 feet.

The forest is of the even-aged mixed hardwood type, so prevalent in Connecticut, with about 40 tree species represented. The trees varied in age from 25 to 40 years with occasional older "wolf" trees. From inquiry and observation it was decided that a portion of each of the four tracts had at some time been cleared and possibly tilled, but it was practically impossible to locate definitely the exact bounds in such cases.

MAPPING THE EXPERIMENTAL AREAS

It seemed advisable, in taking the data on vegetation, to use some systematic method of making a partial tally over a large area rather than a complete tally over a restricted area. To accomplish

this a modification of the Forest Service Standard Valuation Survey was adopted, as follows:

The experimental tracts were laid out as rectangles (Turkey Hill, 20 by 40 chains, 80 acres; Cabin, 20 by 20 chains, 40 acres; Cox, 14 by 36 chains, 50.4 acres, and Reeves, 10 by 40 chains, 40 acres), two parallel sides of which served as base lines from which to start and end the transect or cruise lines which were run perpendicular to the base lines. On the Turkey Hill Tract the transect lines were run with a staff compass, Abney level and trailer tape, and were 5 chains apart, while on the other tracts they were run with a transit, Abney level and tape and were 4 chains apart. The transect lines were marked at 2 chain intervals by a stake monumented with stones. Each transect line was designated by a letter and each stake along a transect line by a number which indicated its distance from the starting point or base. Thus A-10 indicates a point on Line A, 10 chains from the base line. The Abney level and trailer tape were used to correct for slope and to obtain the relative elevation of the ground at the base of the monumented stakes. On the control thus established the next step was to place the skeleton survey on a plane table and carefully draw a topographic map of each tract.

SOIL TYPES OCCURRING ON THE EXPERIMENTAL TRACTS

Detailed soil surveys of the four experimental tracts showed the distribution of soil types to be as presented on the outline maps (Figures 50, 51, 52, and 53). The basis for soil type classification is in accordance with the key to Connecticut soils given in Bulletin 320 of this station.

In order to show the typical characteristics of the various soils, soil pits were excavated at a number of points, where the soils were examined in detail and soil samples were selected for laboratory study. The following descriptions were prepared from these soil profile examinations.

Gloucester fine sandy loam profile, soil pit just southeast of G- -6, Turkey Hill Tract.

Depth	Horizon	Description
0—½ in.	F	Duff from hardwood leaves, moderately decomposing, oak species predominant.
½—1½ ins.	H	Humus accumulations, with only slight admixture of mineral soil, moderately matted, dark brown to gray black, well disintegrated.
1½—1¾ ins.	A_1	Grayish-brown loamy fine sand, with slight tendency toward podsol formation.
1¾—6 ins.	A_2	Medium brown f. s. l., firm but structureless.

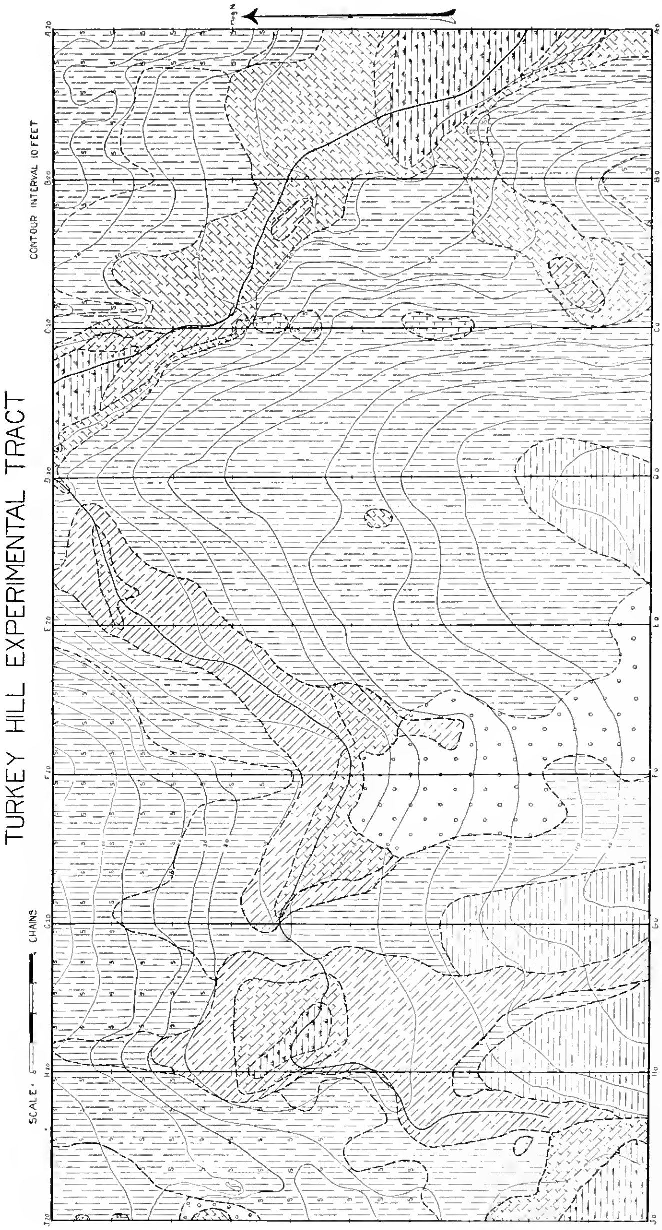

FIGURE 50. Soil and topographic map of the Turkey Hill Experimental Tract, Cockaponset State Forest, Haddam, Conn. For soil and culture legends, see **Figure 53.**

6—11 ins.	A_3	Light yellow brown f. s. l., firm but structureless.
11—17 ins.	B_1	Yellow brown to brownish-yellow, f. s. l., breaking into soft clods upon excavation.
17—25 ins.	B_2	Brownish-yellow f. s. l., slightly lighter in color and less firm than B_1.
25—31 ins.	C_1	Grayish-yellow loamy fine sand, with considerable coarse angular gravel and small stone, moderately loose and open.
31 ins. and below	C_2	Gray to olive gray loamy sand, with much till gravel and stone, chiefly of light colored gneiss rock, loose and open.

Gloucester loam profile, soil pit near G—6, Reeves Tract.

Depth	Horizon	Description
0—½ in.	F	Duff from hardwood leaves, chiefly black birch, hickory, red and black oak.
½—1¼ ins.	H	Humus layer, of "root mor" type, densely matted with mycelial threads and fibrous roots.
1¼—5 ins.	A_2	Brown to dark brown light loam, mellow, with soft crumb structure.
5—11 ins.	A_3	Yellow brown f. s. l. or loam, mellow with soft crumb structure.
11—16 ins.	B_1	Brownish-yellow (lighter in color than A_2) f. s. l. mellow, with soft clods formed on excavation.
16—24 ins.	B_2	Brownish-yellow f. s. l., firm, breaking into soft clods slightly more solid than B_1.
24—30 ins.	C_1	Grayish-yellow f. s. l. to sandy loam, with considerable till gravel, firm, structureless.
30 ins. and below	C_2	Yellowish-gray loamy sand, with much till gravel and rock fragments, loose and open.

Hinsdale fine sandy loam profile, soil pits at F—7, Cox Tract, and B—4, Turkey Hill Tract.

Depth	Horizon	Description
0—¼ in.	F	Duff from white, scarlet and red oak leaves, slightly decomposed.
¼—1¼ ins.	H	Matted, somewhat laminated "Mor" type of humus accumulations, tending toward "raw humus." Some gray mycelial threads, and well developed micorrhyzia on roots.
1¼—3 ins.	A_1—A_2	Grayish-brown f. s. l., firm, slightly laminated Slight tendency to podzol.
3—10 ins.	A_3	Light yellow brown, mellow f. s. l., only slightly granular, easily pulverized with fingers.
10—34 ins.	B_1—B_2	Yellow brown, with slight reddish cast, f. s. l., firm, digs out into soft clods 3-4 inches thick, which easily fall apart to form soft granules.
34—38 ins.	C_1	Grayish-yellow sandy loam, fairly loose, with much disintegrating rock of dioritic type.
38 ins. and below	C_2	Yellowish-gray coarse loamy sand, loose, with much till gravel and broken dioritic stone.

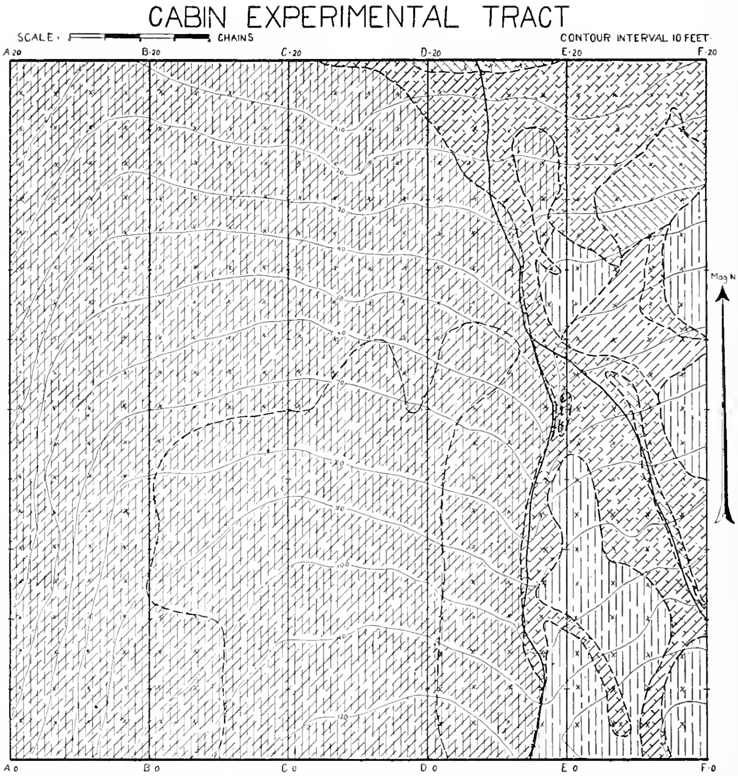

FIGURE 51. Soil and topographic map of the Cabin Experimental Tract, Meshomasic State Forest, Portland, Conn. For soil and culture legends, see Figure 53.

Hinsdale loam profile, soil pits at C—8, Turkey Hill Tract, and at A—B 14¼, Cox Tract.

Depth	Horizon	Description
0—¼ in.	F or A_0	Litter, grayish-brown color, slightly decomposed, hardwood leaves and twigs.
¼—1¼ ins.	H or A_1	Nearly black mellow loam, of "Mull" type with excellent root distribution.
1¼—5 ins.	A_2	Dark brown light loam to f. s. l., mellow, structureless.
5—11 ins.	A_3	Yellow brown f. s. l., mellow, slightly granular to soft clod structure.
11—26 ins.	B_1—B_2	Reddish-yellow brown light loam. Firm, digs out into firm clods 5 or 6 inches diameter of irregular shape.
26—29 ins.	C_1	Yellowish-gray to light yellow brown f. s. l. or loamy fine sand, moderately firm, structureless.
29 ins. and below	C_2	Grayish-yellow to yellowish-gray coarse loamy sand, much till gravel and broken stones of dioritic type, moderately loose to firm.

Haddam fine sandy loam profile, soil pits at C—2 and B—15½, Cabin Tract.

Depth	Horizon	Description
0—½ ins.	F	Litter and duff, chiefly of black birch, maple and white oak leaves.
½—2 ins.	H	Very dark brown, rather "leathery" type of humus layer, much mycelia, and vigorous root distribution between "F" and "H" horizons. "Raw humus" of "root mor" type.
2—7 ins.	A_1—A_2	Medium brown f. s. l., firm, breaks into soft lumps.
7—14 ins.	A_3	Yellow brown to light yellow brown f. s. l., firm, breaks into soft lumps.
14—20 ins.	B_1	Slightly reddish-yellow brown f. s. .l., firm, breaking into moderately compact lumps.
20—28 ins.	B_2	Yellow brown slightly mottled with limonite streaks, fine sandy loam, firm, dense structure.
28—34 ins.	C_1	Yellow brown to light yellow brown with pinkish cast sandy loam, compact.
34 ins. and below		Light brown with pinkish case sandy loam, very compact considerable till, gravel and rock fragments.

Taugwank loam profile, soil pit just south of DE—O, Turkey Hill Tract.

Depth	Horizon	Description
0—¼ ins.	F	Duff of hardwood leaves, rapidly decomposing.
¼—1½ ins.	A_1	Very dark gray brown f. s. l. Firm. Very little structure.
1½—6 ins.	A_2	Slightly grayish-yellow brown f. s. l. Mellow. Soft crumb structure.
6—12 ins.	A_3	Slightly reddish-yellow brown f. s. l. Coarsely granular. Soft.

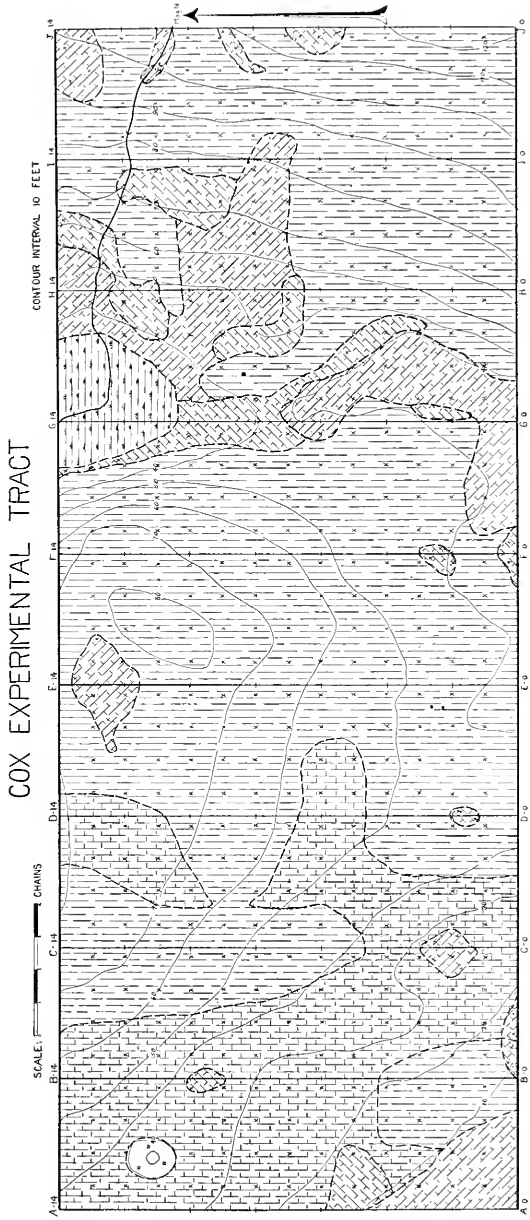

FIGURE 52. Soil and topographic map of the Cox Experimental Tract, Meshomasic State Forest, Portland, Conn. For soil and culture legends, see Figure 53.

12—18 ins.	B	Deep yellow brown, occasionally with slight olive cast, heavy f. s. l. Coarsely granular. Breakage very irregular. Consistency mellow.
18—23 ins.	C_1	Ashen gray with limonite yellow streaks. Heavy sandy loam. Coarsely granular. Firm.
23—28 ins.	C_2	Grayish-brown with reddish streaks of limonite. Heavy sandy loam. Very compact.
28 ins. and below	C_3	Somewhat mottled (brown with reddish tinge and gray brown). Sandy loam with much till gravel. Loosely granular. Moderately compact. Differences in color due to differential weathering.

Peru loam profile soil pit at F—10, Reeves Tract.

Depth	Horizon	Description
0—½ ins.	F	Duff composed chiefly of ash, yellow birch, red maple, aspen and tulip leaves, rapidly decomposing.
½—2 ins.	H or A	Nearly black loam of "mull" type.
2—8 ins.	A_2	Dark brown loam, with excellent natural crumb structure.
8—12 ins.	A_3	Light yellow brown loam or f. s. l., quite mellow.
12—24 ins.	B	Yellow brown loam or sandy loam. Firm.
24—30 ins.	C_1	Mottled rusty yellow and grayish-brown sandy loam, firm to moderately compact. Partially waterlogged.
30 ins. and below	C_2	Too badly waterlogged to examine in detail in the field.

The other soils were not examined in detail, but were mapped on the basis of soil borings, with characteristics as presented in Bulletin 320.

PHYSICAL AND CHEMICAL CHARACTERISTICS OF TYPICAL SOIL PROFILES

The samples of the profiles collected from pits were subjected to certain laboratory determinations, the results of which are briefly presented in the following paragraphs and tables.

Mechanical Analyses

The following table represents the mechanical analyses, by the United States Bureau of Soils method, of the various horizons of the profiles previously described:

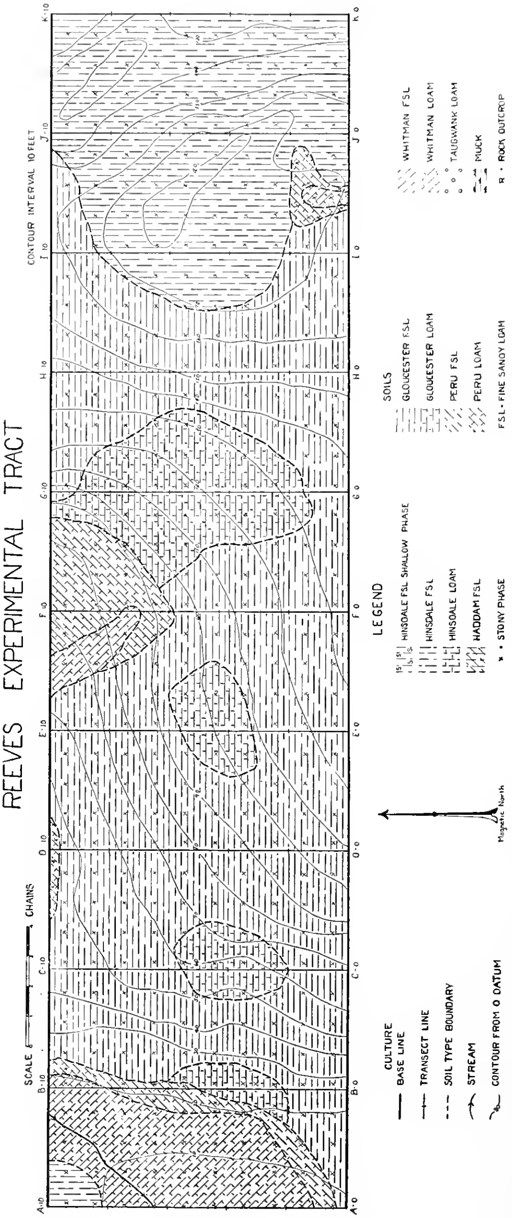

FIGURE 53. Soil and topographic map of the Reeves Experimental Tract, Meshomasic State Forest, Portland, Conn., with soil and culture legends.

TABLE 1. MECHANICAL ANALYSES OF FOREST SOIL PROFILES

		Fine gravel	Coarse sand	Medium sand	Fine sand	Very fine sand	Total sands	Silt	Clay
		per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent
Gloucester f. s. l.	A_2 ...	7.25	14.50	16.25	22.50	17.30	77.80	10.20	12.00
	A_3 ...	10.05	14.95	15.80	22.85	15.95	79.60	8.90	11.50
	B_1 ...	7.00	12.40	17.80	30.60	11.50	79.30	11.20	9.50
	B_2 ...	10.10	16.25	19.65	29.55	11.30	86.85	6.15	7.00
	C_1 ...	10.40	15.90	18.40	27.80	16.05	88.55	9.45	2.00
	C_2 ...	7.40	12.95	15.75	25.60	21.65	83.35	12.15	4.00
Gloucester loam	A_2 ...	2.42	6.77	12.35	34.05	15.35	70.92	15.82	13.25
	A_3 ...	4.12	7.05	11.35	31.40	21.07	75.00	13.60	11.40
	B_1 ...	4.22	7.95	11.07	31.42	21.67	76.35	16.30	7.35
	B_2 ...	6.12	8.07	10.82	28.95	25.37	79.35	15.80	4.82
	C_1 ...	5.45	7.20	10.62	27.50	26.10	76.85	18.32	4.80
	C_2 ...	6.70	8.95	13.20	31.62	23.52	84.00	14.70	1.30
Hinsdale f. s. l.	A_2 ...	2.32	5.08	8.40	27.27	24.85	67.94	15.36	16.70
	A_3 ...	3.30	5.82	8.75	22.76	30.08	70.73	15.96	13.30
	B ...	4.28	6.71	9.43	23.59	33.39	77.41	14.28	8.30
	C_1 ...	8.72	9.26	11.40	33.22	30.10	92.71	3.23	4.05
	C_2 ...	6.55	8.71	12.87	36.50	29.32	93.96	4.39	1.65
Hinsdale loam	A_2 ...	2.31	4.75	8.79	26.22	28.19	70.27	15.37	14.35
	A_3 ...	2.71	5.63	8.87	25.16	32.76	75.14	14.35	10.50
	B ...	2.38	8.93	12.11	33.64	26.46	83.53	5.37	11.10
	C_1 ...	8.25	9.81	13.04	32.67	23.10	86.88	8.92	4.20
	C_2 ...	3.39	5.26	8.22	24.71	31.37	72.96	25.33	1.70
Haddam f. s. l.	A_2 ...	2.96	9.44	15.28	28.95	20.08	76.68	6.67	16.65
	A_3 ...	4.68	9.38	14.12	27.96	23.47	79.62	6.74	13.65
	B_1 ...	5.12	8.12	12.83	28.16	26.70	80.94	5.66	13.40
	B_2 ...	7.10	10.70	14.26	28.88	24.71	85.65	9.80	4.55
	C_1 ...	3.34	9.94	15.08	34.99	26.68	90.04	6.82	3.15
	C_2 ...	5.97	9.67	12.62	27.70	19.96	75.93	9.92	14.15
Taugwank loam	A_2 ...	6.90	16.70	16.65	19.48	11.92	71.65	12.35	16.00
	A_3 ...	6.95	13.60	16.00	17.65	15.33	69.53	13.47	17.00
	B_1 ...	5.95	12.35	15.70	17.10	16.90	68.00	12.00	20.00
	B_2 ...	4.25	11.85	22.55	22.20	14.80	75.65	8.35	16.00
	C_1 ...	5.90	12.15	15.80	20.72	19.85	74.42	12.58	13.00
	C_2 ...	6.60	10.70	15.80	24.25	20.90	78.25	11.75	10.00
Peru loam	A_2 ...	1.38	9.25	12.65	16.05	14.24	53.57	27.53	18.90
	A_3 ...	1.52	5.65	8.74	15.58	23.57	55.06	25.94	19.00
	B ...	2.04	6.93	9.28	17.47	31.18	66.90	19.80	13.30
	C_1 ...	2.87	7.42	7.97	11.50	29.14	58.90	24.60	16.50
	C_2 ...	5.45	11.37	12.40	16.25	23.40	68.87	20.93	10.20

The various profiles, although they exhibit a considerable difference in the textures of the lower horizons, especially in the C_1 and C_2 horizons (unweathered parent material), do not show great differences in the upper horizons. The comparatively narrow textural range of these soils indicates that their chief points of difference are those of mineralogical character of parent material and the moisture conditions as affected by drainage and water table.

Soil Reaction

The soil reaction of the profiles, as measured in terms of pH, is indicated in the following table:

TABLE 2. SOIL REACTION OF FOREST SOIL PROFILES

Horizon	Gloucester f. s. l.	Gloucester loam	Hinsdale f. s. l.	Hinsdale loam	Haddam f. s. l.	Taugwank loam	Peru loam
F	4.43	4.36	3.91	5.46	4.17	5.42	5.46
H or A_1*	4.15	4.00	3.61	5.55*	3.84	4.95*	5.28*
A_2	4.79	5.14	4.20	5.10	4.32	4.98	4.91
A_3	4.91	4.99	4.43	5.45	4.65	5.10	5.57
B_1	4.77	5.07	4.87	5.57	4.86	5.02	5.52
B_2	4.80	5.14	....	....	4.98	5.13	....
C_1	5.23	5.08	5.34	5.38	5.20	5.30	5.60
C_2	5.50	5.29	5.45	5.26	5.30	5.50	....

* The lower organic content of the A_1 horizons of the Hinsdale loam and Peru loam soils is an indication of the admixture of humus and mineral soil in this layer. The higher amounts of organic matter in the lower horizons of the imperfectly drained Peru loam are significant.

Although there is little difference in the reaction of the parent material, there are very striking differences in the upper horizons, particularly in the duff (F layer), unincorporated humus (H layer) and the humus-rich A_1 and A_2 horizons. The Peru, Taugwank and Hinsdale loam soils are significantly less acid. All of these soils fail to show a layer of disintegrated, unincorporated humus H layer, and tend toward the "mull" character in the A_1 horizon. As will be shown later, these soils are more productive than the others as evidenced by the character of the forest growth which they support.

Organic Matter

Five of the profiles were examined for organic matter content, with results as shown in Table 3.

TABLE 3. DISTRIBUTION OF ORGANIC MATTER IN FOREST SOIL PROFILES

Horizon	Gloucester loam	Hinsdale f. s. l.	Hinsdale loam	Haddam f. s. l.	Peru loam
	per cent	per cent	per cent	per cent	per cent
F	82.76	81.60	69.12	74.44	73.97
H or A_1*	62.00	51.09	34.81*	64.36	47.45*
A_2	4.05	8.52	5.30	5.05	12.34
A_3	1.25	2.65	1.57	1.71	3.65
B_1	1.10	0.60	1.20	0.55	3.25
B_2	0.90	....	....	0.47	....
C_1	0.65	0.50	0.60	0.44	1.00
C_2	0.35	0.20	0.30	0.34	....

Total and Replaceable Calcium in Forest Soil Profiles

In view of the fact that calcium is the most abundant ash constituent in forest leaves, it is of interest to present the results of total and exchange (or replaceable) calcium in some of these profiles, as shown in Table 4.

TABLE 4. TOTAL AND REPLACEABLE CALCIUM IN FOREST SOIL PROFILES

Horizon	Total calcium				
	Gloucester loam	Hinsdale f. s. l.	Hinsdale loam	Haddam f. s. l.	Peru loam
	per cent	per cent	per cent	per cent	per cent
F	1.551	0.807	1.793	0.735	1.752
H or A_1*	0.823	0.597	1.359*	0.431	1.672*
A_2	0.411	0.439	0.752	0.623	1.111
A_3	0.447	0.407	0.712	0.599	0.971
B_1	0.563	0.435	0.648	0.535	0.991
B_2	0.603	....	....	0.503	....
C_1	0.655	0.475	0.544	0.479	0.575
C_2	0.515	0.527	0.512	0.583	....

Horizon	Replaceable calcium				
	Gloucester loam	Hinsdale f. s. l.	Hinsdale loam	Haddam f. s. l.	Peru loam
	per cent	per cent	per cent	per cent	per cent
F	0.5208	0.3176	0.7128	0.3470	0.7080
H or A_1*	0.1608	0.0664	0.3920*	0.0995	0.3552*
A_2	0.0093	0.0038	0.0550	0.0058	0.0176
A_3	0.0042	0.0013	0.0249	0.0019	0.0102
B_1	0.0038	0.0013	0.0085	0.0045	0.0093
B_2	0.0029	.....	.....	0.0019	.....
C_1	0.0026	0.0013	.....	0.0029	0.0035
C_2	0.0013	0.0048	0.0006	0.0102	.....

* Indicates A_1 horizon (humus mixed with mineral soil).

The better conditions with respect to both total and replaceable calcium for both the Hinsdale loam and the Peru loam soils are apparent from the above tables. The upper horizons of both the Hinsdale fine sandy loam and the Haddam fine sandy loam soils are low in this element which in forest soils is so important as an ash constituent of leaf material and as a base for the neutralization of acids formed in the decomposition of forest humus. Both of these soils were particularly acid in the upper horizons, as was shown in Table 2.

SURVEY OF FOREST VEGETATION

This subject will be treated under two separate headings.

1. Survey of the major vegetation, which arbitrarily included all woody vegetation 0.6 inch or more diameter breast high. This survey was carried out on all the experimental areas, although the technique was modified slightly during the second season, as will be described later.

2. Survey of the lesser vegetation, which comprised all species both herbaceous and woody, not included under 1. This phase of the study was carried out by H. J. Lutz on the Cabin, Cox and Reeves Experimental Areas during 1927, and is presented by him as a part of this report.

Major Vegetation

Field Technique

Since soil type was to be the basis for classification of the tree growth it was necessary to obtain some form of tally of the tree growth on each type. This could have been done by marking on the ground the intersection of the soil type lines and the transect lines and making a tally of the tree growth directly by soil types as they were encountered on each transect line. The data could then be assembled by units (in this case, soil type) for all transect lines, as is done in valuation survey work.

Inasmuch as it seemed probable that the basis of classification might be changed, and that the experimental tracts might also serve for other types of study, it appeared advisable to use greater refinement in recording the vegetation. This was accomplished by charting the tree vegetation on strips or transects which were 1 rod wide in all cases, but whose length was determined by the length of the transect line. This, of course, varied with the shape of the experimental tracts.

For the Turkey Hill Tract where the transect lines were 5 chains apart the portion of the total area charted amounted to a little more than 5 per cent, while on the other three tracts where the lines were only 4 chains apart the charted area was a little more than 6 per cent of the total area.

Charting was done by a crew of three men, one to plot and the other two to call off the locations of the trees. The instruments used were a two chain trailer tape graduated in links, two poles 8.25 feet long graduated at link intervals, and an army sketch board (with the disc removed) to hold the plotting sheets. Charting was done on cross section paper, to a scale of 1 inch to 10 links. The paper was cut 4 inches wide by 20 inches long. A heavy line was drawn down the center of the sheet to represent the transect line, and a scale in 10 link intervals was marked along the right-hand margin. These sheets were prepared in the office. It can be readily seen that each sheet sufficed for the recording of 2 chains of transect line.

In the field the tape was drawn taut between two of the monumented stakes with the zero end to the rear and tied at both ends. Plotting distances were called off in links as coördinates. Species were called by name and plotted by symbols. Diameters breast high by 1 inch classes were measured with calipers and recorded by arabic numerals. Crown classes were not recorded at Turkey Hill, but were recorded for the other three tracts by the use of Roman numerals indicating (I) dominants, (II) co-dominants, and (III) intermediates. The absence of a Roman numeral indicated an oppressed tree. Sprouts from the same stump were enclosed in a circle.

This method of recording, with variations as noted, was performed on all the experimental tracts. The area on which the vegetation was actually charted in this way, was slightly more than 13 acres. The total number of individual stems plotted was nearly 20,000. Thirty-seven species were represented.

Classification of Field Data

In the field 20 soil types and phases were mapped, but some of these were so nearly alike or were so small in area that for practical purposes a combination was desirable. Degree of stoniness was recognized in the field, but for the purpose of correlation with vegetation, all soils of the same series and textural class received the same designation Peru loam and Peru fine sandy loam were classified together as Peru loam, the difference in textural class being considered of minor importance in this case. Whitman loam and Whitman fine sandy loam were classified together as Whitman loam for the same reason. Rock outcrop occupied only a very

small area and was not included. The ten soil types resulting from this grouping were further combined into four broad groups on the basis of drainage. The final classification for use in the correlation tables was as follows:

1. Lighter well-drained soils
   a. Hinsdale f. s. l., shallow phase—the driest "ridge type" condition with frequent rock outcrop.
   b. Gloucester f. s. l.—a normal medium to light textured upland soil with open substratum.
   c. Hinsdale f. s. l.—same as for Gloucester fine sandy loam.
   d. Haddam f. s. l.—a medium to light textured upland soil, "ridge type" from a topographic standpoint but with high spring water table due to compact sandy substratum.

2. Heavier well-drained soils
   a. Hinsdale loam—somewhat heavier than Hinsdale f. s. l. with good moisture conditions as indicated by "mull" character of surface soil.
   b. Gloucester loam—not appreciably heavier than Gloucester f. s. l., but with better moisture conditions due to slight seepage.
   c. Taugwank loam—a fairly heavy loam with a compact substratum occurring on areas with slight relief and slow but not imperfect underdrainage.

3. Imperfectly drained soils
   a. Peru loam (including Peru f. s. l.)—occurring in broad sloping ravines and on lower hillsides where there is considerable seepage and temporary waterlogging of the soil.
   b. Whitman loam (including Whitman f. s. l.)—occurring in more level ravine and depressions where there is much seepage and water-logging of the soil during wet seasons.

4. Organic soils
   a. Muck—well decomposed organic accumulations more than two feet in depth developed in permanently waterlogged depressions.

On the basis of the soil classification described above, the entire tree tally was next arranged according to the number of trees per acre occurring on each soil type. This data, expressed in percentage, is shown in Table 5. Table 6 shows the area in acres of the soil types as found on the four experimental tracts, together with the actual area charted in each.

TABLE 5. THE DISTRIBUTION OF 25 TREE SPECIES FORMING THE TOTAL STAND[1] ON 10 SOIL TYPES

Tree species	All soils	Hinsdale f. s. l. shallow phase	Gloucester f. s. l.	Haddam f. s. l.	Hinsdale f. s. l.	Hinsdale loam	Gloucester loam	Taugwank loam	Peru loam	Whitman loam[2]	Muck
	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent
Red maple	16.33	14.1	17.8	22.6	14.2	20.7	21.6	7.6	16.4	14.2	55.5
Blue beech	12.66	4.1	5.8	1.8	15.6	1.7	...	22.3	15.6	25.8	9.4
Black birch	9.26	5.6	17.5	21.8	7.6	5.3	17.0	6.3	5.1	1.8	...
White oak	8.72	6.9	8.7	14.1	10.3	17.8	6.1	.4	2.9	2.9	...
Witch hazel[3]	7.70	*	4.2	9.2	6.8	4.1	1.9	*	13.7	8.4	*
Red oak	6.68	10.1	8.1	4.0	7.7	7.7	6.9	5.9	6.1	4.4	...
Yellow birch	5.86	1.5	4.3	1.5	5.0	1.2	17.4	17.6	7.5	12.1	16.1
White ash	4.77	5.7	2.5	.1	5.2	9.3	6.9	8.8	6.4	6.1	...
Pignut-mockernut hickory	4.50	8.6	7.1	4.6	5.0	4.5	7.7	1.3	2.2	.9	...
Dogwood	3.95	10.2	3.8	.5	5.6	7.0	2.7	6.7	2.4	.6	...
Hard maple	3.20	2.9	.4	.8	2.6	4.0	...	14.7	4.8	7.4	...
Iron wood	2.86	2.1	4.4	.2	3.2	.2	1.5	.4	4.7	3.8	...
Black oak	2.67	2.9	3.7	5.5	2.8	3.2	1.7	.8	.5	.6	...
Chestnut oak	2.59	18.8	1.7	6.2	1.2	...	.2	2.9	2.4	.9	...
Scarlet oak	1.50	4.5	1.4	1.3	1.7	2.2	.9	.8	.4	.6	...
Beech	1.16	...	3.7	3.1	.5	3.0	...	...	.13	...	...
Shad bush	1.02	.1	.6	.8	.8	3.0	1.3	.4	1.6	1.3	.8
Sassafras	.89	1.0	.8	.5	1.4	.8	.4	1.3	.9	.4	...
Tulip	.82	...	1.5	.5	.6	.5	2.7	1.3	1.2	.8	...
Cherry	.55	.1	.07	...	.7	...	...	...	1.7	.9	...
Pepperidge	.54	...	.07	.2	.3	...	.9	...	1.2	1.9	1.8
Shagbark hickory	.53	.5	.35	.1	.6	1.9	.4	.4	.5	.5	...
Elm	.41	...	...	...	.13	...	...	...	.3	1.9	12.8
Butternut	.34	.2	.35	.2	.4	.5	1.0	...	.13	.2	...
Alder	.27	...	.28	.2	...	...	.2	...	...	1.3	1.8
Basswood	.14	...	...	...	.06	1.2	.3	...	.3	.4	...
Black ash	.07	...	...	.2	.03	...	...	...	.06	.1	1.8
Total	100.0	99.9	99.1	100.0	100.0	99.8	99.7	99.9	99.1	100.2	100.0
Number of trees per acre	1,468	910	1,437	1,298	1,549	1,335	1,291	952	1,563	1,992	508

[1] Includes all individuals 0.6 inch and over in diameter at breast height.

[2] Includes Whitman f. s. l.

[3] Witch hazel was recorded on the Cabin, Cox, and Reeves Experimental Tracts only. The asterisk in the above columns indicates that the soil type was found on the Turkey Hill Tract, but not on the others, and consequently no entry for witch hazel could be made.

TABLE 6. DISTRIBUTION OF SOIL TYPE AREAS AND CHARTED AREAS USED IN THE PREPARATION OF THE TOTAL STAND TABLE

Soil	Experimental tracts: Turkey Hill, Area of soil type A.	Turkey Hill, Area charted A.	Cabin, Area of soil type A.	Cabin, Area charted A.	Cox, Area of soil type A.	Cox, Area charted A.	Reeves, Area of soil type A.	Reeves, Area charted A.	All tracts, Area of soil type A.	All tracts, Area charted A.
Hinsdale f. s. l. (shallow phase)	12.1	.860	...	...	...	...	...	...	12.1	.860
Gloucester f. s. l.	5.1	.430	...	...	...	...	22.0	1.073	27.1	1.503
Haddam f. s. l.	...	...	28.5	1.750	...	...	...	...	28.5	1.750
Hinsdale f. s. l.	37.2	1.800	3.6	.591	29.8	1.953	8.1	.677	78.7	5.021
Hinsdale loam	.2	.100	...	...	10.2	.601	...	...	10.4	.701
Gloucester loam	...	...	...	...	...	...	4.3	.404	4.3	.404
Taugwank loam	4.0	.250	...	...	...	...	...	...	4.0	.250
Peru loam[1]	6.4	.320	6.7	.416	3.2	.309	2.6	.185	18.9	1.230
Whitman loam[2]	12.1	.510	1.2	.0375	5.8	.467	3.0	.238	22.1	1.2525
Muck	2.9	.230	...	...	1.2	*	...	...	4.1	.230
Rock outcrop	...	...	...	...	.2	...	...	...	.2	...
Total area	80.0	4.500	40.0	2.7945	50.4	3.330	40.0	2.577	210.4	13.2015

As previously stated, the tally of trees on the Cabin, Cox and Reeves Experimental Tracts was made by crown class as well as by diameter and position. It was, therefore, possible to construct a table showing the principal stand (dominant and co-dominant trees) from these data. Table 7 was made similar to Table 5 and with the same list of species although with different arrangement. Table 8 is an area table for the principal stand similar to Table 6. Tables 5 and 7 are only partially comparable because all the soil types do not appear in both tables, it being necessary to exclude the data from the Turkey Hill Tract in the construction of the latter. It would seem, however, that the tables are comparable for the soil type groups represented in both.

* Woody vegetation almost lacking on muck on Cox Tract.
[1] Includes Peru f. s. l.
[2] Includes Whitman f. s. l.

TABLE 7. THE DISTRIBUTION OF 25 TREE SPECIES FORMING THE PRINCIPAL STAND[1] ON SEVEN SOIL TYPES[2]

Tree species	All soils	Gloucester f. s. l.	Haddam f. s. l.	Hinsdale f. s. l.	Hinsdale loam	Gloucester loam	Peru loam[3]	Whitman loam
	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent
Red oak	16.17	18.45	5.86	20.27	27.57	12.15	19.21	13.33
Red maple	12.58	9.71	13.19	10.81	7.03	9.39	20.20	21.90
White oak	11.23	8.25	17.95	10.36	16.22	8.29	4.43	4.76
Black oak	7.19	9.71	7.69	8.56	11.99	4.42	.99	....
White ash	5.84	2.91	.37	6.31	14.56	8.29	5.42	19.52
Scarlet oak	5.39	5.83	3.66	6.30	12.43	2.76	2.96	7.14
Chestnut oak	5.39	1.46	10.99	3.60	....	....	11.33	....
Yellow birch	4.49	4.37	.73	4.50	....	13.81	6.90	13.33
Pignut-mockernut hickory	4.49	4.05	5.13	4.50	2.70	6.63	1.48	3.33
Tulip	2.70	1.94	1.09	3.15	....	6.63	5.91	4.76
Hard maple	1.80	.49	.73	2.25	....	....	2.96	3.33
Shagbark hickory	.90	....	.37	1.35	2.70	....	1.97	.48
Butternut	.90	1.94	.37	.45	....	4.42	....	....
Cherry	.45	....	....	.45	....	....	1.97	1.90
Ironwood	.45	....	....	.90	....	....	1.48	.48
Beech	.40	.49	.73	.45	....	....	....	....
Dogwood	.31	....	....	.45	....	....	.99	....
Basswood	.27	....	....	.45	1.08	....	.49	.48
Black ash	.22	....	....	....	....	....	.99	1.43
Sassafras	.22	....	....	.45	....	....	.49	....
Pepperidge	.22	....	....	.45	....	....	.99	....
Blue beech	.22	....	.37	.45	....	....	....	....
Alder	.09	....	....	....	....	....	....	1.43
Witch hazel	.09	....	.37	....	....	....	....	....
Elm	....	....	....	....	....	....	....	....
Shadbush	....	....	....	....	....	....	....	....
Total	99.98	99.21	100.00	99.97	99.96	99.99	100.03	99.98
Number of trees per acre	223	206	273	222	185	181	203	210

[1] Includes dominant and co-dominant trees only.

[2] Data for Cabin, Cox and Reeves Experimental Tracts only.

[3] Includes Peru f. s. l.

TABLE 8. DISTRIBUTION OF SOIL TYPE AREAS AND CHARTED AREAS USED IN THE PREPARATION OF THE PRINCIPAL STAND TABLE

	Experimental Tract[1] Cabin		Cox		Reeves		All tracts	
	Area of soil type A.	Area charted A.	Area of soil type A.	Area charted A.	Area of soil type A.	Area charted A.	Area of soil type A.	Area charted A.
Gloucester f. s. l. ..	...	...	...	...	22.0	1.073	22.0	1.073
Haddam f. s. l.	28.5	1.750	...	...	...	....	28.5	1.750
Hinsdale f. s. l. ...	3.6	.591	29.8	1.953	8.1	.677	41.5	3.221
Hinsdale loam	...	...	10.2	.601	...	...	10.2	.601
Gloucester loam ..	...	...	...	...	4.3	.404	4.3	.404
Peru loam[2]	6.7	.416	3.2	.309	2.6	.185	12.5	.910
Whitman loam ...	1.2	.0375	5.8	.467	3.0	.238	10.0	.7425
Muck	...	...	1.2	*	...	...	1.2	....
Rock outcrop	...	...	.2	†	...	...	.2	....
Total area	40.0	2.7945	50.4	3.330	40.0	2.577	130.4	8.7015

Only 27 (actually 28 because two hickories are combined) of the 37 species charted are shown in the tables. Of the remaining nine, gray birch and aspen were omitted, the former because it was apparent that it occurred in response to light and the latter because it was found chiefly on old charcoal pits. Chestnut was not included due to its susceptibility to the bark disease. The others, white birch, cedar, hemlock, white pine, butternut, hickory and locust, were left out because of extremely small representation.

For further comparisons, the tree species are shown in Table 9 arranged according to their abundance on four rather broad soil groups. This was done in order to minimize some of the irregularities existing in Tables 5 and 7 and also to group together the species that make up the bulk of the stand on the four soil groups. It should be clearly understood that abundance, as used in Table 9, is a relative, not an absolute term. For instance, considering the forest as a whole, elm is not abundant, forming less than one-half of one per cent of the entire stand. However, on muck, elm is relatively abundant since it comprises nearly 13 per cent of the stand. The opposite is true for black birch.

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[1] Data from Turkey Hill Tract not included.
[2] Includes Peru f. s. l.
* Woody vegetation almost lacking on muck.
† Transect line did not cross this type.

TABLE 9. THE RELATIVE ABUNDANCE OF 27 TREE SPECIES ON FOUR BROAD SOIL GROUPS.[1]

Relative abundance: I, very abundant; II, abundant; III, well represented; IV, poorly represented; V, very poorly represented, and VI, missing.

Soil group

	Lighter well-drained soils	Heavier well-drained soils	Imperfectly drained soils	Organic soils
I	Chestnut oak Scarlet oak		(Blue beech)	Elm Red maple
II	{ Pignut hickory { Mockernut hickory[2] Black oak Red oak	Tulip	Basswood Yellow birch Hard maple Red maple (Witch hazel)	Black ash Yellow birch Pepperidge (Alder)
III	Black birch Red maple (Dogwood)[3] (Witch hazel)	White ash Basswood Yellow birch Shagbark hickory { Pignut hickory { Mockernut hickory Hard maple Red maple Black oak Red oak Scarlet oak White oak (Blue beech) (Shadbush)	Black ash White ash Cherry Elm Chestnut oak Red oak Pepperidge Tulip (Alder) (Ironwood) (Shadbush)	(Blue beech)
IV	Beech Yellow birch Butternut Cherry Shagbark hickory Hard maple White oak Pepperidge Sassafras Tulip (Alder) (Blue beech) (Ironwood) (Shadbush)	Beech Black birch Butternut Cherry Pepperidge Sassafras (Dogwood) (Ironwood) (Witch hazel)	Butternut { Pignut hickory { Mockernut hickory Shagbark hickory Sassafras (Dogwood)	(Shadbush)
V	White ash Basswood	Chestnut oak (Alder)	Beech Black birch Black oak Scarlet oak White oak	
VI	Black ash Elm	Black ash Elm		White ash Basswood Beech Black birch Butternut Cherry { Pignut hickory { Mockernut hickory Shagbark hickory Hard maple Black oak Chestnut oak Red oak Scarlet oak White oak Sassafras Tulip (Dogwood) (Ironwood) (Witch hazel)

[1] For description of these groups see page 692.
[2] Pignut hickory and mockernut hickory are considered as one species.
[3] Species in parentheses are under-story species.

Tables 10, 11, 12, and 13 for white oak, red oak, yellow birch, and white ash, respectively, were made up directly from the original charting sheets. Each plot represents the portion of a transect line between two monumented stakes, that is, an area one rod wide and eight rods long, or 1/20 of an acre. Two hundred and sixty-five such plots were recorded. However, some of them included two or more soil types and consequently were not suitable for the above tables.

TABLE 10. THE DISTRIBUTION OF WHITE OAK ON 10 SOIL TYPES ACCORDING TO THE NUMBER OF TREES PER 1/20 ACRE PLOT

Soil	Percentage of 1/20 acre plots				Number of plots
	With no trees	With 1-5 trees	With 6-20 trees	With 21-80 trees	
Hinsdale f. s. l. shallow phase	27	53	20	..	15
Gloucester f. s. l.	6	58	36	..	31
Haddam f. s. l.	3	46	41	10	39
Hinsdale f. s. l.	10	39	47	4	85
Hinsdale loam	..	..	100	..	12
Gloucester loam	14	72	14	..	7
Taugwank loam	100	..	..	..	4
Peru loam	85	15	..	..	13
Whitman loam	56	38	..	6	16
Muck	100	..	..	..	5
					227

TABLE 11. THE DISTRIBUTION OF RED OAK ON 10 SOIL TYPES ACCORDING TO THE NUMBER OF TREES PER 1/20 ACRE PLOT

Soil	Percentage of 1/20 acre plots				Number of plots
	With no trees	With 1-5 trees	With 6-20 trees	With 21-80 trees	
Hinsdale f. s. l. shallow phase	50	30	10	10	10
Gloucester f. s. l.	15	50	33	2	34
Haddam f. s. l.	26	69	5	..	39
Hinsdale f. s. l.	10	55	31	4	78
Hinsdale loam	36	36	28	..	11
Gloucester loam	12	63	25	..	8
Taugwank loam	25	75	.	..	4
Peru loam	20	50	30	..	10
Whitman loam	7	75	18	..	16
Muck	100	..	..	..	5
					215

TABLE 12. THE DISTRIBUTION OF YELLOW BIRCH ON 10 SOIL TYPES ACCORDING TO THE NUMBER OF TREES PER 1/20 ACRE PLOT

Soil	Percentage of 1/20 acre plots: With no trees	With 1-5 trees	With 6-20 trees	With 21-80 trees	Number of plots
Hinsdale f. s. l. shallow phase	86	14	..	..	14
Gloucester f. s. l.	41	45	14	..	29
Haddam f. s. l.	82	15	3	..	39
Hinsdale f. s. l.	53	23	19	5	82
Hinsdale loam	100	..	..	..	11
Gloucester loam	25	38	25	12	8
Taugwank loam	25	..	75	..	4
Peru loam	25	33	34	8	12
Whitman loam	15	46	30	9	13
Muck	80	..	20	..	5
					217

TABLE 13. THE DISTRIBUTION OF WHITE ASH ON 10 SOIL TYPES ACCORDING TO THE NUMBER OF TREES PER 1/20 ACRE PLOT

Soil	Percentage of 1/20 acre plots: With no trees	With 1-5 trees	With 6-20 trees	With 21-80 trees	Number of plots
Hinsdale f. s. l. shallow phase	57	29	7	7	14
Gloucester f. s. l.	58	32	10	..	31
Haddam f. s. l.	95	5	..	..	39
Hinsdale f. s. l.	39	41	16	4	85
Hinsdale loam	10	45	45	..	11
Gloucester loam	14	14	72	..	7
Taugwank loam	25	50	25	..	4
Peru loam	23	69	8	..	13
Whitman loam	25	38	37	..	16
Muck	100	..	..	..	5
					225

These four species were selected because they form a considerable portion of the stand and are represented on all soils except muck. The tables indicate the percentage of plots on which the species is missing and also on which the representation is low, medium or high. Figure 54 presents the data in graphic form.

The Relationship of Tree Species to Soil Type

Following is a brief discussion of the relationship of each of the 27 tree species listed in Tables 5 and 7 to the soil types on which they were found. These notes were made up from the material presented in the several tables and figures, and from other data not incorporated in this report.

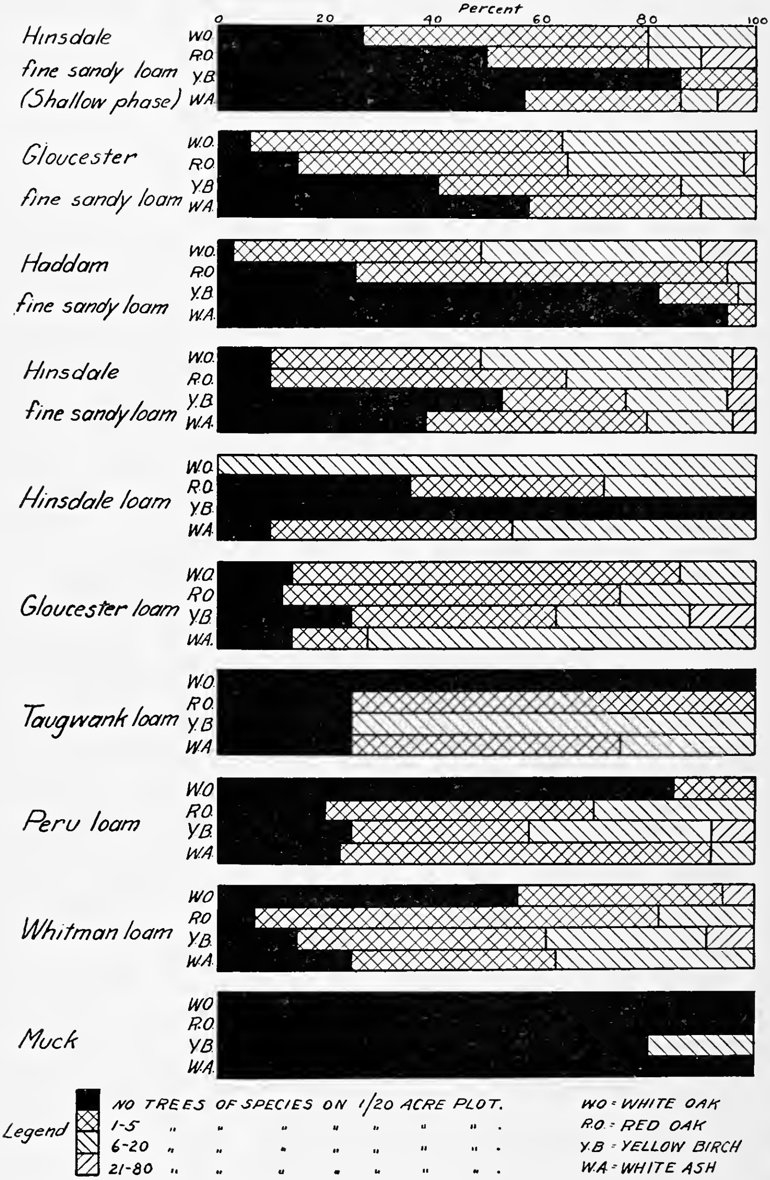

FIGURE 54. The distribution of white oak, red oak, yellow birch, and white ash on 10 soil types according to the number of trees per 1/20 acre plot. Data from Tables 10, 11, 12 and 13.

Red maple (*Acer rubrum,* L.). This species had the greatest abundance and most uniform distribution of any species encountered, forming 16 per cent of the total and 13 per cent of the principal stand. It showed no particular preference for any soil group except muck, where it formed 55 per cent of the stand. It occurred least abundantly on Taugwank loam, the reason for this not being apparent.

Blue beech (*Carpinus caroliniana,* Walt.). Blue beech was found on all soils, forming 13 per cent of the total stand. Its distribution among the several soil types was somewhat erratic, being most abundant on the imperfectly drained and organic soils and on Taugwank loam. As it seldom reached into the upper canopy it appeared only as a very small component of the principal stand.

Black birch (*Betula lenta,* L.). This was another abundant species, forming 9 per cent of the total and 18 per cent of the principal stand. It was found on all soils except muck, but its representation was significantly low on the imperfectly drained soils and on shallow phase Hinsdale fine sandy loam. Its preference seemed to be for the better grades of the lighter well-drained soils. Its abundance, however, was probably determined to a considerable extent by the past history of the stand.

White oak (*Quercus alba,* L.). White oak formed 9 per cent of the total and 11 per cent of the principal stand. It was not found on muck, is least abundant on the very driest and on the imperfectly drained soils and most abundant on the normal upland soils. By reference to Table 10 and Figure 54 it can be seen that the largest percentage of 1/20 acre plots having more than 5 trees are on the normal upland soils, and also that the fewest number of plots with no trees occurred on these soils. It was more abundant on Haddam fine sandy loam and Hinsdale fine sandy loam and loam than it was on Gloucester fine sandy loam and loam. The reason for this is not clear unless it is the effect of a greater amount of ferro-magnesium minerals in the Haddam and Hinsdale series.

Witch hazel (*Hamamelis virginiana,* L.). The data for this species are for the Cabin, Cox and Reeves Tracts only. In total numbers, this witch hazel was also a fairly abundant species, forming 8 per cent of the total stand, but since it does not attain tree size, it is not shown in the principal stand. It was most abundant on the imperfectly drained soils, least so on the heavier well-drained soils, and well represented on the lighter well-drained soils, especially on Haddam fine sandy loam. The reason for this is not clear unless it is that the Haddam soil is peculiar in that, although it possesses the characteristics of a dry soil, it has a high water table temporarily in the spring season.

Red oak (*Quercus rubra,* L.). Red oak formed 7 per cent of the total and 16 per cent of the principal stand and was found on all soils except muck. Its distribution among the 10 soil types

was quite even, although it seemed to show some preference for the lighter well-drained soils with the exception of the Haddam soil. It was rather low on Whitman loam and most abundant on Hinsdale fine sandy loam shallow phase. For comparison, reference is made to Table 11 and Figure 54 where it will be found that the percentage of 1/20 acre plots having more than 5 trees was highest for the lighter well-drained soils, Haddam excepted. It is also interesting to note that the percentage of 1/20 acre plots having no trees is relatively low on all soils.

Yellow birch (*Betula lutea,* Michx.). This species formed about 6 per cent of the total and 4 per cent of the principal stand. Yellow birch was found both in the total and principal stands most abundantly on the heavier well-drained soils, on the imperfectly drained soils and on muck. It was quite low on Haddam fine sandy loam and on shallow phase Hinsdale fine sandy loam, thus indicating the ridge type character of the former. The percentage of 1/20 acre plots (see Table 12 and Figure 54) having no trees varies greatly among the several soil groups, indicating a fairly high degree of intolerance in the choice of sites. Its poor distribution on Hinsdale loam is unexplained. As contrasted with white oak the percentage of 1/20 plots having more than five trees was highest among the soils favorable to excessive moisture conditions.

White ash (*Fraxinus americana,* L.). White ash formed 5 per cent of the total and 6 per cent of the principal stand. In general it exhibited much the same characteristics as yellow birch, although it was not found on muck and was rather more evenly distributed among the several soils than the latter species. It also formed a very low percentage of the stand on Haddam fine sandy loam. In view of its distribution elsewhere its abundance on Hinsdale fine sandy loam, shallow phase, seems peculiar. Referring to Table 13 and Figure 54, however, it can be seen that on this soil type, 57 per cent of the 1/20 acre plots had no trees and that 7 per cent, or 1 plot, had more than 5 trees and another 7 per cent, or 1 plot, had more than 20 trees. The stand per acre of white ash was only 52, and, if more than 20 stems were found on one 1/20 acre plot, the stand per acre on the balance of this soil type was quite low. Moreover, about 40 per cent of the stand consisted of trees in the 1 inch class, which will probably be unable to stand future competition with other species.

Pignut hickory (*Hicoria glabra,* Britt.) and **mockernut hickory** (*Hicoria alba,* Britt.). Together these two species formed about 4 per cent of both the total and principal stands. In general they tended to diminish in abundance from the driest to the wettest soils and were not represented on muck. The exception to this is on Gloucester loam, where the abundance was quite high.

Dogwood (*Cornus florida,* L.). This is an under-story species

that formed about 4 per cent of the total stand but was seldom a component of the principal stand. Its distribution among the several soils was very erratic. It was quite abundant on the driest and very poorly represented on the wettest sites.

Hard maple (*Acer saccharum,* Marsh.). Hard maple formed 3 per cent of the total and 2 per cent of the principal stand. This species showed a very decided tendency to increase in abundance with increase in soil moisture, although it was not found on muck. Its absence on Gloucester loam is unexplained. Its fairly high abundance on Hinsdale fine sandy loam, shallow phase, was due to the presence of small seedlings that will probably not survive.

Ironwood (*Ostrya virginiana,* K. Koch.). Ironwood formed about 3 per cent of the total stand, but was seldom represented in the principal stand. Its distribution among the several soil types was quite erratic with no apparent preference. It was absent on muck.

Black oak (*Quercus velutina,* Lam.). Black oak formed 3 per cent of the total and 7 per cent of the principal stand. It was best represented on the well-drained soils, least abundant on the imperfectly drained soils and absent on muck.

Chestnut oak (*Quercus prinus,* L.). Chestnut oak formed about 3 per cent of the total and 5 per cent of the principal stand. It showed a marked tendency to dominate the stand on the driest sites. This was especially pronounced on shallow phase Hinsdale fine sandy loam and on Haddam fine sandy loam. For all other soils it can be generally said that chestnut oak was poorly represented. An apparent exception to this is its high representation in the principal stand on Peru loam (Cabin Tract) adjacent to Haddam fine sandy loam, on which it was also abundant. It was not found elsewhere on the Peru soil in significant amounts. Its high abundance on both the Haddam and Peru soils, on the Cabin Tract, was probably as much due to past history as to any soil preference.

Scarlet oak (*Quercus coccinea* Moench.). Scarlet oak formed about 1 per cent of the total and 5 per cent of the principal stand. In general this species was most abundant on the lighter well-drained soils. Apparent exceptions to this are its presence in considerable amounts on Hinsdale loam and Whitman loam in the principal stand. This is chiefly to be accounted for, however, by the abundance of scarlet oak on the Cox Tract, where it averaged more than 10 per cent of the stand.

Beech (*Fagus americana,* Sweet.). Beech was only a very small component of either the total or principal stand. It was confined to well-drained soils where it occurred in local spots of almost pure beech reproduced by root suckers.

Shadbush (*Amelanchier canadensis,* T. and G.). Shadbush formed 1 per cent of the total stand. It was found to some extent

on all soils, but was most abundant on the heavier well-drained and imperfectly drained soils. It is also found on muck.

Sassafras (*Sassafras sassafras,* Karst.). This species formed about 1 per cent of the total stand, but was seldom present in the upper canopy. It was fairly evenly distributed on all soils except muck.

Tulip (*Liriodendron tulipifera,* L.). Tulip formed less than 1 per cent of the total and 3 per cent of the principal stand. It was found to some extent on all but the driest soils, but was most abundant on soils having a high moisture content. It was not found on muck.

Cherry (*Prunus serotina,* Ehrh.). Cherry had a very scattering distribution but was most abundant on the imperfectly drained Peru and Whitman soils. It was not found on muck.

Pepperidge (*Nyssa sylvatica,* Marsh.). The distribution was quite similar to cherry except that it was found on muck.

Shagbark hickory (*Hicoria ovata,* Britt.). This tree was fairly evenly distributed on all soils, with a slight possible preference for the more moist well-drained soils.

Elm (*Ulmus americana,* L.). This species was confined almost entirely to the wettest soils, being most abundant on muck.

Butternut (*Juglans cinerea,* L.). Butternut was found in small quantities on all soils with no particular preference shown.

Alder (*Alnus rugosa,* Du Roi.). Alder had a scattering distribution on a number of soils, but reached its greatest abundance on Whitman loam and muck.

Basswood (*Tilia americana,* L.). Basswood occurred scatteringly on a number of soils but was most abundant on the heavier well-drained group.

Black ash (*Fraxinus nigra* Marsh.). Black ash was a tree of very limited occurrence and was confined almost wholly to muck soils.

Another classification of the tree species represented is shown in Table 9. In this table the soils are classified in four rather broad groups and the tree species listed under each group according to relative abundance, which is assumed to indicate the preference of a species for some particular class of soils.

On the lighter well-drained soils chestnut and scarlet oak were very abundant, red oak and black oak were abundant, and red maple and black birch were well represented. Abundant understory species were witch hazel and dogwood. White ash, basswood, elm and black ash were either poorly represented or entirely missing. The remaining 17 species were usually represented, but seldom in appreciable quantity. The vegetation on this group of soils may be termed an oak-hickory association.

The heavier well-drained soils formed the meeting place for a large number of species. No species was particularly abundant.

Tulip, although never a large component of any stand, seemed to show a marked preference for this group of soils. Thirteen species were well represented. Elm and black ash were not found. The remaining 11 species were usually present but did not form a significant portion of the stand.

The imperfectly drained soils were similar to the heavier well-drained soils in that a large number of species (17) made up the bulk of the stand. As contrasted with the latter, five species, that is, blue beech, red maple, yellow birch, basswood and witch hazel exhibited a strong preference for these soils. Apparently witch hazel showed inconsistency because it was also well represented on the lighter well-drained soils, which is not true of the other five species. Significant also is the fact that no species was absent from these soils.

The organic soil, muck, is chiefly characterized by the small number of species making up the stand. Only eight species were represented at all and of these, red maple, elm and yellow birch made up 85 per cent of the stand, with red maple predominant.

The Lesser Vegetation

Field Technique

The transect lines established in connection with the survey of the major vegetation were used as a basis for the survey of the lesser vegetation. Quadrats 1 meter square were established at each monumented station along the transect lines at intervals of about 40.2 meters (2 chains). A wooden frame which enclosed exactly 1 square meter was used as an aid in accurately establishing the quadrats. See Figure 55. The frame was demountable, and fastened at the four corners with wing nuts so it could be placed around large trees or shrubs, which sometimes occurred within the quadrats. Holes were drilled along the sides of the frame to receive cross wires which divided the enclosed area into either four or eight sections as might be desired. This division of the square meter into sections greatly facilitated the study of the vegetation.

On each quadrat the following data were secured:

1. List of all species in each of the following three size classes.

Size class designation	
1	Herbs, low shrubs, and tree seedlings, 0 to .60 meters high.
2	Tall herbs, shrubs, and small trees, .61 to 1.80 meters high.
3	High shrubs and trees, 1.81 meters high to 1.3 centimeters (0.5 inches) in diameter at breast height.

This classification is purely arbitrary and intended only to serve as a more or less natural basis in separating the vegetation for study.

2. Number of individuals of each species in each of the three size classes recognized.

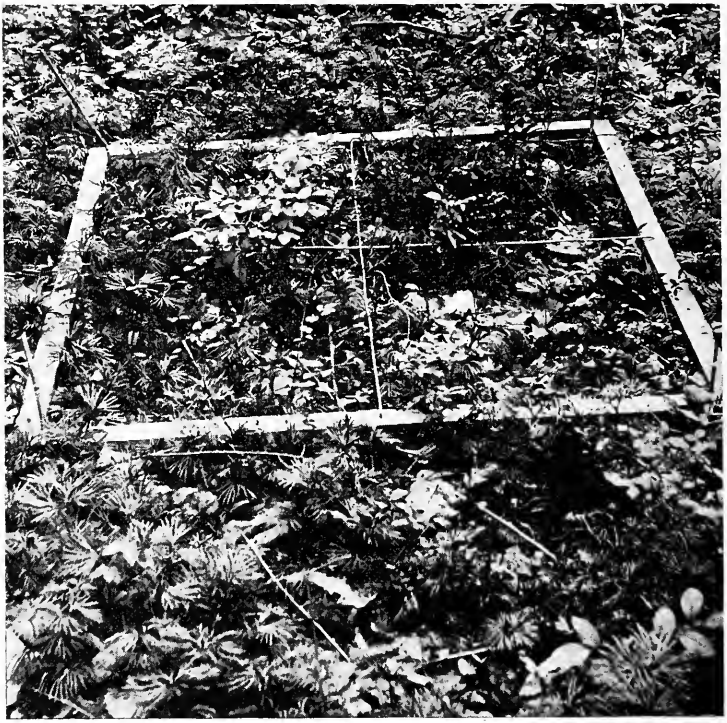

FIGURE 55. Wooden frame in position for studying lesser vegetation. The chief species are *Vaccinium pennsylvanicum, Lycopodium complanatum,* and *Gaylussacia baccata.*

3. Percentage of area covered by the individual species in each size class.

4. An ocular estimate of the density of crown cover in the dominant or main stand, which is hereafter designated as size class 4.

Ten degrees of crown density were recognized, as follows:

Degree of density	Density of crown cover in per cent
1	0 to 10
2	11 to 20
3	21 to 30
4	31 to 40
5	41 to 50
6	51 to 60
7	61 to 70
8	71 to 80
9	81 to 90
10	91 to 100

For convenience the following indices of abundance and frequency were recognized in this study.

Index of frequency or abundance	Frequency or abundance in per cent
1	0 to 10.0
2	10.1 to 20.0
3	20.1 to 30.0
4	30.1 to 40.0
5	40.1 to 50.0
6	50.1 to 60.0
7	60.1 to 70.0
8	70.1 to 80.0
9	80.1 to 90.0
10	90.1 to 100.0

The 7 soil types encountered are designated in Tables 15, 16, and 17, according to the following system.

Soil type designation	Soil type
50—	Whitman loam
43—	Peru loam
11—	Gloucester loam
14—	Hinsdale loam
33	Haddam f. s. l.
14	Hinsdale f. s. l.
11	Gloucester f. s. l.

The nomenclature here adopted is that of Sudworth[1] for the tree species and that of Gray's Manual[2] for the shrubs and herbs.

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[1] Sudworth, G. B. Check list of the forest trees of the United States, their name and ranges. U. S. Dept. Agri., Misc. Circ. 92. 1927.

[2] Robinson, B. L., and Fernald, M. L. Gray's new manual of botany. Seventh edition. 1908.

Analysis of Data

The first step in analyzing the data was to classify the quadrats on the basis of their location with reference to experimental tracts and soil types. Table 14 shows the number of quadrats studied on each soil type within the three experimental tracts.

Table 14. Distribution of Quadrats on Experimental Tract and Soil Types

Soil type	Number quadrats measured — Cabin Tract	Cox Tract	Reeves Tract
Whitman loam	..	11	5
Peru loam	6	6	6
Hinsdale loam	..	15	..
Gloucester loam	..	..	7
Gloucester f. s. l.	..	..	25
Hinsdale f. s. l.	9	43	16
Haddam f. s. l.	38	..	..

Number of species and individuals. The average number of species and individuals per unit area of one square meter was determined for each soil type. Average values are shown in Figure 56. The number of species and individuals on the Peru loam (Cabin experimental tract) was so extremely low that it suggested an abnormal vegetational condition. Probably this apparently abnormal condition is the result of past influences such as fire, cutting, or some other disturbing agency. Both the number of species and the number of individuals on this soil type on the Cabin tract were much lower than on any other soil type. For these reasons, data secured on the Peru loam soil type in the Cabin experimental tract are not included in the averages shown in Figure 56.

The average number of species and the average number of individuals on the Whitman loam and Peru loam soils was distinctly higher than on Hinsdale loam, Gloucester loam, Gloucester fine sandy loam, Hinsdale fine sandy loam, and Haddam fine sandy loam soils. The first two of the above soil types are slowly drained and the others are rapidly drained. From the standpoint of forest growth, the slowly drained soils are considered better forest sites than the rapidly drained soils.

Figure 56 indicates that there is a close relationship between rapidity of soil drainage and the average number of species and individuals per unit area. The three fine sandy loam soils (Haddam, Hinsdale and Gloucester) all stand low in the number of species and individuals. Gloucester loam and Hinsdale loam hold somewhat higher positions in this respect. Peru loam and Whitman loam, both slowly drained soils, stand highest. The moisture relations appear to be an important factor in controlling vegetational development on these soils. Soil moisture has long been

recognized by plant ecologists as being of prime importance in controlling plant distribution and development.

Foresters generally recognize that poor sites usually support a greater number of individual trees per unit area than good sites.

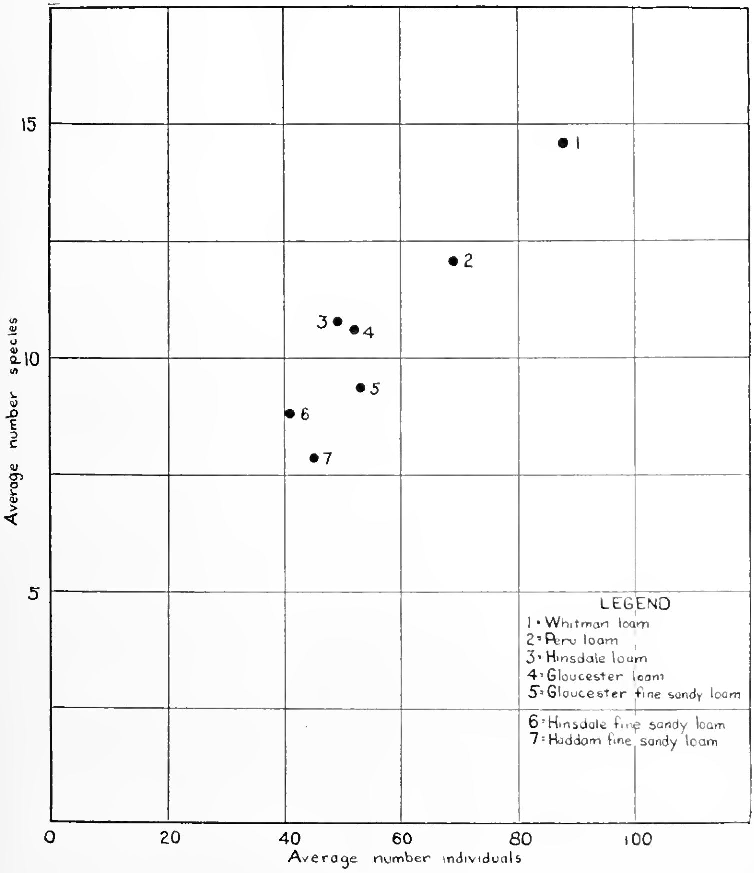

FIGURE 56. Showing the average number of species and average number of individuals per square meter on seven soil types.

This condition appears to be exactly reversed in the case of the lesser vegetation. Relatively poor sites have a low number of individuals and relatively good sites have a higher number of individuals. An explanation of the conditions noted in the case of the lesser vegetation is that on the better sites the growth factor is present in excess of the demands of the major vegetation. This permits the development of lesser vegetation that is rich both

in number of species and in number of individuals. Competition between individuals of the lesser vegetation is probably not as intense and eliminative as it is in the case of the major vegetation.

Indicator plants. The idea of using plants as indicators of environmental conditions is not new. The ancients noted that certain plants could be used as indicators since they were usually associated with particular soil conditions. In more recent times, during the past quarter century, many careful investigations have been made of plants as indicators of environmental conditions. Hilgard,[1] Shantz,[2] Hesselman,[3] Bornebusch,[4] Cajander,[5] Wherry,[6] and others have made outstanding contributions to the literature of indicator plants. Carter,[7] Veatch[8] and others have studied native vegetation with particular reference to its value as an indicator of soil type.

In the present study abundance values were determined for each species on each soil type. Because of the length, complete tables of abundance are not presented. Table 15 presents values for all species having an index of abundance of 2 or more. These values are averages for three experimental tracts. The relatively small number of species appearing in Table 11 indicates that this selection was rather close.

TABLE 15. OCCURRENCE OF SPECIES OF RELATIVELY HIGH ABUNDANCE ON VARIOUS SOIL TYPES

Species	Soil type designation Abundance index 50—	43—	11—	14—	33	14	11
Dicksonia punctilobula	*	*	3	*	*	*	*
Maianthemum canadense	2	2	*	*	2	*	2
Mitchella repens	*	*	2	2	*	*	2
Rhododendron nudiflorum	*	2	*			*	*
Vaccinium vacillans		*	*	*	2	*	2
Gaylussacia baccata		*	*	*	2	*	*

[1] Hilgard, E. W. Soils. 1906.

[2] Shantz, H. L. Natural vegetation as an indicator of the capabilities of land for crop production in the Great Plains area. Bureau of Plant Industry, Bull. 201. 1911.

[3] Hesselman, Henrik. On the effect of our regeneration measures on the formation of saltpetre in the ground and its importance in the regeneration of coniferous forests. Meddelanden Från Statens Skogsförsöksanstalt. Häfte 13-14, Band II, p. 923-1076. Stockholm. 1916-17.

[4] Bornebusch, H. C. Skovbundsstudier (Disquisitions on flora and soil of Danish woodlands) Det. Forstl. Forsogsvaesen i. Danmark 8: 1-148. 1923-1926. 1923.

[5] Cajander, A. K. The theory of forest types. Helsinki. 1926.

[6] Wherry, E. T. The soil-reaction preferences of certain plant orders. Jour. Wash. Acad. Sci., 17: 148-149. 1927.

[7] Carter, W. T. A study of native vegetation as related to soil classification. Amer. Soil Survey Assoc. Rpt.

[8] Veatch, J. O. Reconstruction of forest cover based on soil maps. Mich. Quarterly Bull. 10: 116-126. East Lansing. 1928.

* Indicates occurrence but with abundance index less than 2.

Frequency values were determined for each species in the same way. Average values are presented in Table 16. Only species having an average frequency index of 6 or more are shown. Table 17 lists all species encountered on quadrats in the survey of the lesser vegetation on the three experimental tracts, together with average frequency indices for each species on each soil type.

Maianthemum canadense is indicated in Table 15 as being relatively abundant on four soil types, ranging from the slowly drained Whitman loam to the rapidly drained Gloucester fine sandy loam. This species was present on all soil types. It appears that soil type as recognized is not a controlling factor in determining the abundance of this species. The frequency index of *Maianthemum* on Whitman loam is 7. However, in view of its general occurrence on the other soil types *Maianthemum* appears to have but little if any indicator value.

TABLE 16. OCCURRENCE OF SPECIES OF RELATIVELY HIGH FREQUENCY ON VARIOUS SOIL TYPES

Species	Soil type designation						
	50—	43—	11—	14—	33	14	11
	Frequency index						
Polystichum acrostichoides	*	*	*	6	*	*	
Dicksonia punctilobula	*	*	8	*	*	*	*
Oakesia sessilifolia	*	*	*	7	*	*	*
Maianthemum canadense	7	*	*	*	*	*	*
Rubus hispidus	8	*	*	*	*	*	*
Aralia nudicaulis	*	*	8		*	*	*
Lysimachia quadrifolia		*	6	*	*	*	*
Mitchella repens	9	*	6	6	*	*	*
Aster spp.	6		*	*	*	*	*
Psedera quinquefolia	7	*	*	*	*	*	*
Gaylussacia baccata		*	*	*	7	*	*
Vaccinium vacillans		*	*	*	6	*	7
Viburnum acerifolium		*	*	6	*	*	*
Acer rubrum	*	*	6	*	6	*	6
Fraxinus americana	7	*	*	7	*	*	*

Dicksonia puntilobula was relatively abundant on the Gloucester loam soil and has a high frequency index which indicates that it is well distributed. The data for this species were taken on the Reeves experimental area. It is believed by the writer that the somewhat disturbed condition of the forest on this soil type accounts for the high abundance and frequency of *Dicksonia*. *Dicksonia* has little if any value as an indicator of soil type, but may be regarded as an indicator of disturbances within the forest, particularly disturbances that open up the crown canopy.

Mitchella repens was present on all soil types. On the Gloucester loam, Hinsdale loam, and Gloucester fine sandy loam soils this species has an abundance index of 2. The frequency

* Indicates occurrence but with frequency index less than 6.

index of *Mitchella* on Gloucester loam and Hinsdale loam soils was 6, but on the Gloucester fine sandy loam was 5. On Whitman loam soil the frequency index of *Mitchella* was 9. The fairly common occurrence of *Mitchella* on all soil types makes it a species of little if any indicator value for specific soil types.

Rhododendron nudiflorum is indicated as having an abundance index of 2 and a frequency index of 2 on Peru loam soil. However, *Rhododendron* was rather well distributed over nearly all the soil types so its value as an indicator of any one is rather low.

Vaccinium vacillans had an abundance index of 2 on the Haddam fine sandy loam and Gloucester fine sandy loam soils. On both of these soils it has a frequency index of 6 or more. The absence of this species on Whitman loam and its relatively high frequency on the rapidly drained soils indicates that it may have value as an indicator of soils of the latter group.

Gaylussacia baccata had an abundance index of 2 and a frequency index of 7 on Haddam fine sandy loam soil. As in the case of *Vaccinium vacillans, Gaylussacia* appears to have value as an indicator of rapidly drained soils, particularly Haddam fine sandy loam.

In addition to the above, other plants having somewhat lower abundance and frequency values may serve as indicator species. The occurrence of the following species seems to be indicative of soils in the rapidly drained soil group: *Hieracium paniculatum, Epipactis pubescens, Lysimachia quadrifolia, Melampyrum lineare, Juniperus virginiana, Quercus montana, Rubus villosus, Celastrus scandens, Pyrola americana, Pyrola elliptica, Chimaphila maculata, Chimaphila umbellata,* and *Corylus rostrata.* The occurrence of the following species seems to be indicative of soils in the slowly drained group, that is, Whitman loam and Peru loam. *Impatiens biflora, Asplenium Felix-femina, Smilax rotundifolia, Viola conspersa, Viola papilionacea, Viola blanda, Osmunda cinnamomea, Onoclea sensibilis, Sisyrinchium angustifolium,* and *Alnus incana* occurred chiefly on Whitman loam soil. *Lycopodium lucidulum* and *Clethra alnifolia* were chiefly confined to the Peru loam soil.

TABLE 17. FREQUENCY OF SPECIES ON VARIOUS SOIL TYPES

Herbaceous species	Soil type designation 50—	43—	11—	14—	33	14	11
	Frequency index						
Phegopteris hexagonoptera	1	..	..	..	..	..	..
Pteris aquilina	..	1	..	3	2	1	1
Asplenium Felix-femina	3	..	..	..	..	1	..
Polystichum acrostichoides	3	1	2	6	1	2	..
Aspidium noveboracense	2	2	2	2	1	2	1
Aspidium marginale	1	..	..	..	..	1	..
Dicksonia punctilobula	2	2	8	4	1	3	3
Onoclea sensibilis	2	..	..	..	..	1	..
Osmunda Claytoniana	3	1	3	..	1	1	2
Osmunda cinnamomea	3	2	..	1	..	1	1
Lycopodium lucidulum	..	1	..	..	..	..	..
Lycopodium obscurum	1	..	..	..	1	1	2

TABLE 17—*Continued.*

	Soil type designation						
	50—	43—	11—	14—	33	14	11
	Frequency index						
Lycopodium complanatum	..	1	2	..	4	1	1
Panicum spp.	1	1	..	2	..	1	..
Poa spp.	..	..	..	..	..	1	..
Carex spp.	3	1	5	4	5	4	4
Arisaema triphyllum	4	..	..	3	..	2	1
Uvularia perfoliata	1	1	3	2	..	2	1
Oakesia sessilifolia	5	3	5	7	3	4	5
Lilium philadelphicum	..	..	..	..	..	1	..
Smilacina racemosa	..	..	..	3	..	1	1
Maianthemum canadense	7	2	2	3	2	3	4
Medeola virginiana	1	1	..	..	3	1	1
Hypoxis hirsuta	1	1	..	1	..	..	..
Sisyrinchium angustifolium	1	..	..	..	..	..	..
Cypripedium acaule	2	..	..	..	..	..	..
Pogonia verticillata	..	..	2	2	..	1	1
Epipactis pubescens	..	..	..	..	..	1	..
Comandra umbellata	..	..	..	..	..	1	..
Anemonella thalictroides	1	..	..	..	..	1	..
Hepatica triloba	1	..	..	..	..	..	..
Anemone quinquefolia	1	..	..	..	..	1	..
Actaea alba	..	..	2	..	..	..	..
Fragaria virginiana	..	..	..	..	..	1	..
Potentilla canadensis	2	..	..	..	1	1	..
Rubus hispidus	8	2	2	5	3	2	2
Rubus villosus	..	..	..	..	..	1	..
Agrimonia gryposepala	..	..	..	..	..	1	..
Amphicarpa monoica	1	1	..	2	..	1	1
Geranium maculatum	4	1	..	1	..	1	1
Impatiens biflora	1	..	..	..	..	..	..
Viola papilionacea	3	..	..	..	..	..	..
Viola palmata	..	..	..	..	..	1	..
Viola blanda	5	..	2	..	..	1	1
Viola canadensis	..	..	2	..	..	..	1
Viola conspersa	2	..	..	..	..	..	..
Circaea lutetiana	1	..	..	..	..	1	..
Aralia nudicaulis	5	2	8	..	3	3	5
Chimaphila umbellata	..	..	..	3	1	1	1
Chimaphila maculata	..	..	..	4	2	2	2
Pyrola chlorantha	..	..	..	1	..	..	..
Pyrola elliptica	..	..	..	..	..	1	1
Pyrola americana	..	1	5	4	2	1	1
Monotropa uniflora	..	1	..	2	..	1	1
Lysimachia quadrifolia	..	1	6	4	4	3	4
Trientalis americana	..	1	..	..	1	1	..
Collinsonia canadensis	..	..	..	1	..	1	1
Melampyrum lineare	..	..	..	..	1	1	2
Galium asprellum	1	..	..	..	..	1	..
Mitchella repens	9	2	6	6	1	3	5
Houstonia caerulea	..	..	..	..	1	1	..
Solidago spp.	3	..	..	2	1	2	2
Aster acuminatus	1	..	..	..	..	1	..
Aster spp.	6	..	5	2	2	2	3
Erigeron pulchellus	..	..	..	..	..	1	..
Prenanthes trifoliolata	4	..	..	..	1	1	1
Prenanthes sp.	..	1	..	..	..	..	..
Hieracium paniculatum	..	..	2	..	..	1	1

TABLE 17—*Continued.*

Shrubby species	Soil type designation / Frequency index						
	50—	43—	11—	14—	33	14	11
Smilax rotundifolia	1	..	..	..	..	..	..
Smilax glauca	..	1	2	..	1	1	..
Corylus rostrata	..	..	5	5	1	2	2
Alnus incana	1	..	..	..	..	..	..
Benzoin aestivale	1	..	..	..	..	1	1
Rosa humilis	1	..	..	..	1	1	..
Rhus Toxicodendron	2	1	..	..	1	1	..
Ilex verticillata	2	..	..	..	..	1	..
Celastrus scandens	..	..	..	2	..	2	..
Psedera quinquefolia	7	3	2	1	1	2	1
Vitis sp.	1	..	..	..	..	1	..
Cornus paniculata	1	..	..	..	..	..	..
Clethra alnifolia	..	1	..	..	..	..	..
Rhododendron nudiflorum	2	2	5	..	..	1	2
Kalmia latifolia	..	..	..	..	1	1	..
Kalmia angustifolia	..	..	..	..	..	1	..
Lyonia ligustrina	1	2	..	1	2	1	2
Gaylussacia baccata	..	1	2	4	7	3	4
Vaccinium pennsylvanicum	..	1	..	..	4	1	..
Vaccinium vacillans	..	1	5	4	6	5	7
Vaccinium corymbosum	..	..	..	1	1	1	1
Diervilla Lonicera	..	..	..	..	1	..	..
Viburnum acerifolium	..	3	3	6	2	3	3
Viburnum cassinoides	1	..	..	1	..	..	1

Tree species	Soil type designation / Frequency index						
	50—	43—	11—	14—	33	14	11
Pinus strobus	..	..	..	..	1	..	..
Juniperus virginiana	..	..	..	1	..	1	..
Hicoria cordiformis	..	..	..	..	..	1	..
Hicoria ovata	..	..	..	..	..	..	1
Hicoria glabra	..	1	3	..	2	1	2
Carpinus caroliniana	3	1	..	..	..	1	1
Ostrya virginiana	..	..	..	..	..	1	1
Betula lenta	4	1	..	..	1	1	1
Betula lutea	2	..	2	..	..	..	1
Betula populifolia	1	1	..	..	..	1	..
Fagus grandifolia	..	..	..	..	1	..	..
Castanea dentata	..	1	3	1	2	1	2
Quercus borealis maxima	..	2	5	..	1	2	3
Quercus coccinea	..	..	..	1	1	1	1
Quercus velutina	..	1	..	..	2	1	1
Quercus alba	1	..	2	2	2	2	4
Quercus montana	..	..	..	..	2	1	..
Ulmus americana	1	..	..	..	..	1	..
Liriodendron tulipifera	..	1	..	..	1	1	1
Sassafras variifolium	1	..	..	2	1	1	..
Hamamelis virginiana	..	3	2	..	2	1	2
Amelanchier canadensis	..	..	..	..	1	1	1
Crataegus sp.	..	..	..	..	..	1	..
Prunus virginiana	..	..	..	1	..	..	..
Prunus serotina	3	1	..	2	1	1	1
Acer saccharum	..	1	..	..	1	2	..
Acer rubrum	4	3	6	3	6	3	6
Tilia glabra	..	..	..	..	..	..	1
Cornus florida	..	1	..	..	..	1	1
Fraxinus americana	7	2	3	7	1	3	2

Average degree of cover. The average degree of cover, or density in each of the lower vegetational layers and in the main

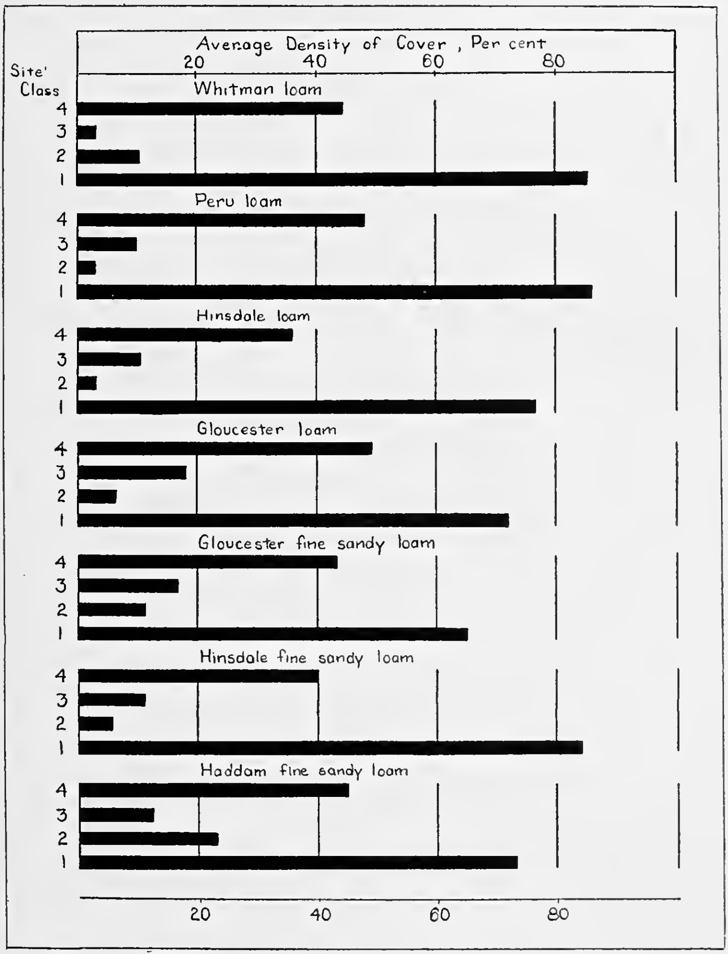

FIGURE 57. Showing average density of cover in the various vegetational layers on seven soil types.

forest canopy, was determined for each soil type. Figure 57 presents the summarized data graphically.

In the lowest vegetational layer, that is, vegetation 0 to .60 meters in height, it appears that in general the slowly drained soils have the denser cover. In the second layer, or vegetation .61 to

1.80 meters in height, soil type seems to have little influence on vegetational density. Possibly the density is slightly greater on the rapidly drained than on the slowly drained soils. In the third vegetational layer, or vegetation 1.81 meters in height to 1.3 centimeters (.5 inches) in diameter at breast height, it is quite clear that the density is greatest on the rapidly drained soils and least on the slowly drained soils.

The main crown canopy, considered as the fourth vegetational layer, did not vary greatly on the various soil types. With the exception of the stand on Hinsdale loam soil the average degree of density of crown canopy was about 5. Evidently soil type does not greatly influence degree of density or cover in the various forest layers studied.

SUMMARY AND CONCLUSIONS

During 1926 and 1927 four experimental tracts, aggregating 210 acres, were laid out for the purpose of studying the relationship between soil type and vegetation. Woody vegetation 0.6 inch D. B. H. and over was charted on transects crossing each tract at regular intervals. Thirteen acres, or approximately 6.5 per cent of the entire area, were thus charted. The lesser vegetation, consisting of all woody plants less than 0.6 inches in diameter and all herbaceous plants, was studied by means of quadrats laid out at regular intervals along the transect lines on three of the experimental tracts.

On four representative tracts of 40 acres or more each, 10 distinct soil types were found, of which no tract had less than four types.

The tree vegetation on any considerable area of natural mixed hardwood forest in Connecticut is composed of about 40 species in the upper and lower canopy. Ten species (red maple, black birch, white oak, red oak, yellow birch, white ash, hickories, hard maple, black oak, and chestnut oak) form 65 per cent of the stand. Blue beech, witch hazel, dogwood and ironwood form an additional 25 per cent.

Correlation of a given tree species with a specific soil type was largely unsuccessful. By classifying the soils into four broad groups on the basis of moisture conditions, some correlation is evident, although some of this is more apparent than real. Chestnut oak, scarlet oak, red oak, black oak, hickories, and black birch form most of the stand on the lighter well-drained soils. This is probably due as much to the low abundance of other species on these soils as to any preference for the soils. Chestnut oak and red oak are also quite well represented on all other soil groups except the muck. Red maple is found on all soils. Scarlet oak,

black oak, and black birch exhibit a fairly regular tendency to decrease as soil moisture increases.

Elm and black ash show the most positive correlation. These two species are entirely absent from all but the imperfectly drained and organic soils. The very high percentage of red maple on muck is largely due to its adaptability and the scarcity of other species on this soil.

White ash, yellow birch, hard maple, basswood, blue beech and pepperidge exhibit a fairly high degree of correlation, which increases fairly regularly from the dry to the imperfectly drained soils. Yellow birch, pepperidge and blue beech persist on muck.

For the study of the lesser vegetation 187 quadrats 1 meter square were laid out at regular intervals along transect lines on the Cabin, Cox and Reeves experimental tracts. The data obtained indicate that the slowly drained soils (Whitman loam and Peru loam) support a greater number of both species and individuals of herbaceous and shrubby plants than the rapidly drained soils (Hinsdale loam, Gloucester loam, Gloucester fine sandy loam, Hinsdale fine sandy loam, and Haddam fine sandy loam). This condition, particularly in regard to the number of individuals, is the reverse of what is usually found in the case of forest tree growth, that is, the better soils usually support a smaller number of trees per unit area than do the poorer soils.

An attempt was made to discover species that would have value as indicators of the various soil types. This was largely unsuccessful. However, broad soil divisions, based on soil water relations, may be indicated by the occurrence of species generally regarded as mesophytes or xerophytes. The slowly drained Whitman and Peru loam characteristically support such mesophytic plants as *Alnus incana, Asplenium Felix-femina, Viola blanda, Lycopodium Lucidulum,* and *Clethra alnifolia.* The other soils, considered as rapidly drained and drier, usually support such xero-mesophytic or xerophytic species as *Vaccinium vacillans, Gaylussacia baccata, Hieracium paniculatum, Melampyrum lineare, Quercus montana, Rubus villosus,* and *Corylus rostrata.*

Lack of apparent correlation between certain plants and specific soil types may be explained in a number of ways. Possibly two or more of the soil types recognized may be biologically equivalent. Biologically equivalent soil types would be expected to support much the same kind of vegetation even though they were designated by different soil type names. A further consideration in explaining the lack of a close correlation between soil type and vegetation is that of compensating factors. The climatic conditions within the region in which the studies were made are generally favorable to the development of fairly luxuriant plant growth. The ecological margin of safety in the region is rather

wide and it is reasonable to suppose that the general excellence of climatic factors may compensate to some extent for poverty of certain soil conditions. This would be particularly true within rather narrow liimts of soil variation. In addition, fire and other factors, chiefly the result of the intervention of man, have upset the balance of nature, and the composition of the current vegetation undoubtedly has been in some measure influenced by these factors which unfortunately are extremely difficult or impossible to evaluate.

Probably the most successful work on plant indicators has been done in regions where conditions for plant growth were not generally favorable, that is, where the ecological margin of safety was rather narrow.

The above conclusions were reached as a result of studies made in relatively immature forest stands that have been subjected to varying kinds of treatment. Further study will be necessary to show whether these conclusions are applicable to mature stands that have developed undisturbed by unnatural agencies.

Present Status of the Investigation

Inasmuch as the data of the vegetation on the four experimental tracts was recorded very carefully in such a way that a remeasurement at any time would result in further data strictly comparable to that taken in 1926 and 1927, the four tracts were set aside by permission of the State Forester, for use by the Station for permanent sample plots. The stations on the transect lines were monumented with stakes and stones and the boundaries were well marked. These tracts, as a whole or in part, can be made to serve admirably for almost any silvicultural investigation where a permanent initial record is desired.

PART II

THE RELATION OF SOIL FACTORS TO THE GROWTH OF RED PINE IN PLANTATIONS

As has been shown in Part I the results of attempted forest-soil correlations in immature natural mixed hardwood stands were inconclusive. After careful consideration of the problem it seemed that the influence of the soil factors should be reflected in the development of red pine (*Pinus resinosa*) plantations, which have been established in many parts of the state under a wide range of site conditions during the last 30 years.

Some preliminary work along this line had been done by Haig[1] in a study of colloidal content as an indicator of site quality. The present study represents a more detailed investigation under a wider range of soil conditions.

OBJECT AND SCOPE OF INVESTIGATION

The object of the present study was the evaluation of the importance of the more readily recognized soil factors in enhancing or retarding the growth of red pine in terms of the height growth of the dominant trees in the stand (site index). The soil factors selected for attempted correlation were:

1. Soil characteristics observed in the field:
    a. Soil series.
    b. Soil texture.
    c. Character of the subsoil.
    d. Character of the Ao-1 horizon
    e. Hydrogen ion concentration (determined in both field and laboratory).

2. Soil characteristics analyzed in the laboratory:
    a. Silt plus clay and colloidal content.
    b. Moisture equivalent.
    c. Total nitrogen content.
    d. Nitrification and ammonification.

The field seasons of 1928 and 1929 were spent in securing height-age data for the preparation of site index tables for red pine and in making soil descriptions and collecting samples for later analysis in the laboratory. Practically every red pine planta-

[1] Haig, I. T. Colloidal content and related soil factors as indicators of site quality. Yale Univ. School Forestry, Bull. 1929.

tion in the state that had reached an age of 12 years or more was visited and one or more stations established for taking measurements. These stations are referred to throughout the text as plots, although in reality they are not plots because they have no definite area. It was considered necessary in view of the correlations to be attempted later that the soil description and analyses be representative of the area from which tree measurements were taken. Plots were obtained over as wide a geographical range and on as many different soils as possible. Care was taken to secure measurements only in stands that had been free from hardwood competition. The age of the plantations ranged from 12 to 30 years but a large percentage of them were from 15 to 20 years old. Data were taken on more than 200 plots. However, some of these were later found to be unsuitable so that finally only 194 were used in the material herewith presented. Each location selected was given a number that was used to identify all data on trees and soils taken at that place.

FIELD TECHNIQUE

At each plot the total heights of 10 or more dominant trees were measured. Total age was determined from office records of the establishment of the plantations. In many cases, in addition to data on total height and total age, measurements of height were taken at other ages (secured by counting back a selected number of internodes from the tip of the tree and subtracting this from the total age). This procedure not only furnished additional height-age data for use in preparing the site index tables, which will be described later, but also enabled the reading of several site index values for the same plot from these tables.

The soils on each plot were studied as fully as possible by profile examinations and the series and textural class of the soil determined on the basis of field identification by approved soil survey methods. The character of the litter and humus decomposition was carefully noted. Soil acidity tests, using the La Motte-Morgan soil testing kit, were made in the field and supplemented by more exact electrometric tests of representative samples in the laboratory. Samples of the A_{1-2} horizon, to be described later, were collected from each plot and the F-layer, or duff, was sampled on certain plots.

GENERAL CHARACTER OF THE SOILS

Plots in practically all cases were located on areas that had once been cleared, and either cultivated or pastured for a considerable period before being abandoned and subsequently set to pines. The

cultivation that may have been practiced on such fields could not have been of an intensive type, if the agricultural history of the region is any criterion. An occasional crop of corn, with long intervening periods in grass hay, was the common practice on such lands. Lime or commercial fertilizers were rarely used until comparatively recent years. Barnyard manure was usually applied fairly heavily at infrequent intervals. A long period of pasturing without manurial treatment usually followed the abandonment of cultivation, before the pine plantations were established.

Although the previous treatment on these areas should not have left any abnormal fertility, from a nutritional standpoint, the soil profile in these young pine plantations could not be expected to have the same character in the upper horizons as permanent forest lands that had never been cleared.

The duff, humus and upper mineral soil layers were mixed by the plow with the organic matter subjected to conditions favorable for rapid decomposition. The structure of the soil to several inches depth was altered by cultivation and the trampling of grazing animals.

Thus soil horizon variations that may have existed in their original forested state in these plantations were largely obliterated, and the resultant profile shows only the action of a few years of needle-droppings and the root effects of the young pine trees upon a soil that shows only three distinct layers.

A. Mineral soil darkened by organic matter incorporations from root and crop residues. Usually of dark brown color, from 5 to 7 inches deep, and containing less organic colloidal material than B.

B. Mineral soil containing no incorporated organic residues, usually yellow brown, brownish-yellow or reddish-yellow brown color, depending chiefly upon the mineral characteristic of the parent material; some accumulation of inorganic colloidal material except in excessively sandy profiles; depth extending to about 24 to 30 inches below surface.

C. Parent material, little affected by soil forming processes, usually consisting of either stratified or unstratified glacial debris, containing clay, sand, gravel or angular rock fragments in varying proportions, depending upon the glacial geology of the area.

The plantation with its litter and duff layers has usually modified the A horizon slightly in its upper half inch or so, producing a slight but perceptible graying of the color. It would thus be possible to recognize both an A_1 and A_2 horizon. Since in sampling these were not separated, the collected samples were designated as A_{1-2}.

The variations in soil texture, the mineral character, and geologic history of the parent material are indicated by soil series and soil type designations.[1]

[1] Morgan, M. F. The Soils of Connecticut. Conn. Agri. Exp. Sta., Bull. 320. 1930.

PREPARATION OF THE SITE INDEX TABLES

For the purposes of correlating the growth of red pine with the several soil factors, it was necessary to establish some basis by which the various stands selected for investigation could be compared. Since height growth of the dominant trees is the most

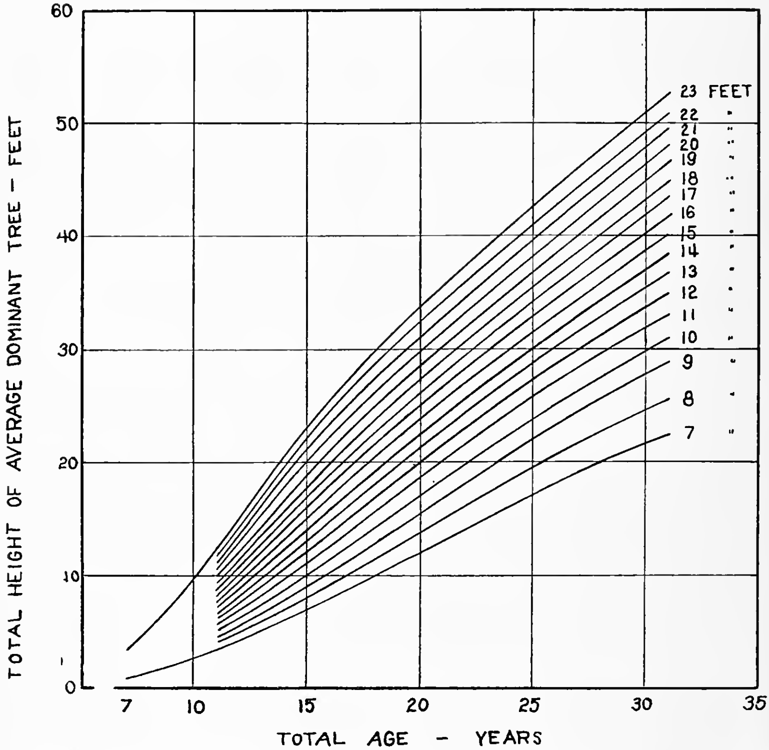

FIGURE 58. Polymorphic site index curves for planted red pine. Plotted from Table 18. Classification age, 15 years. Based on the measurement of more than 2,000 trees.

generally accepted criterion[1] of the quality or growing capacity of the site it was decided to use this as a basis. A set of site index curves was constructed from the height-age data taken when the plots were established. A paper describing in detail the construction of these site index curves has been prepared by Henry Bull,[2]

[1] Munns, E. N., and others. Report of committee on methods of preparing volume and yield tables. Jour. Forestry, 24: 653-666. 1926.

[2] Bull, Henry. The determination of site quality in young red pine plantations by the use of polymorphic curves. Manuscript on file at the Conn. Agr. Exp. Sta. 1930.

formerly of the Station. This paper is still in manuscript form, but it is anticipated that it will soon appear as a technical article in the *Journal of Agricultural Research.* For this reason, only a brief description of the methods used in the construction of the curves, together with the curves themselves, tables derived from them and a description of their application will be included in this paper.

With the height-age data taken in the field a series of anamorphic site index curves was first constructed after the method of Bruce.[3] These curves were similar to those used by the U. S. Forest Service in the construction of volume and yield tables, except that the basis or classification age was only 15 years. It was found, however, that these curves did not accurately portray the progress of height growth and another set of curves (called "polymorphic" to distinguish them from the anamorphic curves of Bruce) was constructed based on seven graduating curves (anamorphosis uses only one). These curves more nearly portray the trend of height growth on all sites and for all ages within the limits of the curves than do anamorphic curves. The polymorphic curves are shown in Figure 58 and tables read from them are shown in Table 18. It should be clearly understood that total age means age of stock plus period since planting and also that only dominant trees were measured.

Essentially what the curves and table do is to convert the data on height and age for any plantation into a figure called site index, which represents the height which that plantation had, or will have at the classification age, in this case 15 years. To use the table, measure the heights of 10 or more dominant trees, average the results, determine the age, and look up the site index value in the table. If possible, several heights corresponding to several different ages (determined by counting, back from the tip) should be taken and the corresponding site index values looked up in the table. Several values can thus be obtained for comparison and average.

It will be noted in Figure 58 that below 15 years the curves are rising rather rapidly, and consequently small errors in taking heights or determining age result in comparatively large errors in site index. These errors diminish as height and age increase. Although site index may be read from the table in tenths of feet, final values should be rounded off to the nearest foot unless extreme care is taken in securing the height-age data. Ordinarily values to the nearest foot will be as close as will be needed.

In connection with the construction of the polymorphic curves Bull also worked out a method for determining site index when the total age is unknown. At present it is known as the "Three-

[3] Bruce, D. A method of preparing timber yield tables. Jour. Agr. Research, 32: 543-557. 1926.

TABLE 18. SITE INDEX TABLE FOR PLANTED RED PINE, BASED ON POLYMORPHIC CURVES[1, 2]

Site index, feet	Total age in years: 7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
	Total height of average dominant tree, in feet																								
7	0.9	1.4	2.1	2.8	3.5	4.3	5.2	6.1	7.0	7.9	8.8	9.7	10.7	11.7	12.8	13.9	15.0	16.1	17.2	18.2	19.2	20.0	20.8	21.6	22.3
8	1.1	1.6	2.4	3.2	4.0	4.9	5.9	6.9	8.0	9.0	10.1	11.2	12.4	13.6	14.8	16.0	17.2	18.4	19.6	20.8	21.9	23.0	23.9	24.8	25.6
9	1.3	1.9	2.7	3.6	4.5	5.5	6.6	7.8	9.0	10.2	11.4	12.6	13.9	15.2	16.5	17.9	19.3	20.6	21.9	23.2	24.5	25.6	26.7	27.7	28.6
10	1.4	2.2	3.0	4.0	5.0	6.1	7.4	8.7	10.0	11.3	12.7	14.1	15.5	16.9	18.3	19.7	21.1	22.5	23.9	25.2	26.5	27.8	28.9	30.0	30.9
11	1.6	2.4	3.3	4.4	5.5	6.7	8.1	9.5	11.0	12.5	14.0	15.5	17.0	18.5	20.0	21.4	22.8	24.2	25.6	27.0	28.3	29.6	30.8	31.9	32.9
12	1.8	2.6	3.6	4.8	6.0	7.3	8.8	10.4	12.0	13.6	15.2	16.8	18.4	19.9	21.4	22.9	24.4	25.8	27.2	28.6	30.0	31.3	32.6	33.8	34.9
13	2.0	2.8	3.9	5.2	6.5	7.9	9.5	11.2	13.0	14.7	16.4	18.0	19.7	21.3	22.8	24.3	25.8	27.3	28.7	30.1	31.5	32.9	34.2	35.4	36.5
14	2.1	3.0	4.2	5.6	7.0	8.6	10.3	12.1	14.0	15.8	17.5	19.2	20.9	22.5	24.1	25.7	27.3	28.8	30.2	31.6	33.0	34.4	35.8	37.1	38.3
15	2.3	3.2	4.5	5.9	7.5	9.3	11.1	13.0	15.0	16.8	18.6	20.3	22.0	23.7	25.3	26.9	28.5	30.0	31.5	33.0	34.5	36.0	37.4	38.8	40.1
16	2.4	3.4	4.7	6.3	8.0	9.9	11.9	13.9	16.0	17.9	19.7	21.4	23.1	24.8	26.4	28.0	29.6	31.2	32.8	34.4	36.0	37.5	39.0	40.4	41.8
17	2.6	3.6	5.0	6.7	8.5	10.5	12.7	14.9	17.0	18.9	20.7	22.4	24.1	25.8	27.4	29.1	30.7	32.4	34.0	35.7	37.3	38.9	40.5	42.0	43.4
18	2.8	3.8	5.3	7.1	9.1	11.2	13.5	15.8	18.0	19.9	21.7	23.4	25.2	26.9	28.6	30.3	32.0	33.7	35.4	37.1	38.8	40.4	42.0	43.5	44.9
19	2.9	4.1	5.6	7.5	9.6	11.9	14.3	16.7	19.0	21.0	22.8	24.6	26.4	28.1	29.8	31.5	33.2	34.0	36.6	38.3	40.0	41.7	43.4	45.0	46.5
20	3.0	4.3	6.0	8.0	10.2	12.6	15.1	17.6	20.0	22.1	24.0	25.8	27.6	29.3	31.1	32.8	34.6	36.3	38.0	39.7	41.4	43.1	44.8	46.4	47.9
21	3.2	4.5	6.3	8.4	10.8	13.3	16.0	18.6	21.0	23.2	25.2	27.0	28.8	30.6	32.4	34.1	35.9	37.6	39.4	41.1	42.8	44.5	46.2	47.8	49.4
22	3.4	4.8	6.6	8.8	11.4	14.1	16.8	19.5	22.0	24.3	26.4	28.3	30.1	31.9	33.7	35.5	37.3	39.1	40.9	42.6	44.3	46.0	47.7	49.3	50.9
23	3.5	5.0	7.0	9.3	12.0	14.9	17.7	20.4	23.0	25.4	27.6	29.6	31.5	33.3	35.1	36.9	38.7	40.5	42.3	44.1	45.8	47.5	49.2	50.9	52.5

[1] Classification age: 15 years.
[2] The block enclosed by heavy black lines contains probable values. There were no data for this section.

feet-to-the-top" method. The site index values for use with this method were derived from Table 18 by interpolation, taking as a unit only that section of the tree above 3 feet. In Figure 59 these interpolated values are plotted for direct use.

To apply this method in the field measure the total height of the tree and subtract three feet. Ascertain the age at a point 3 feet

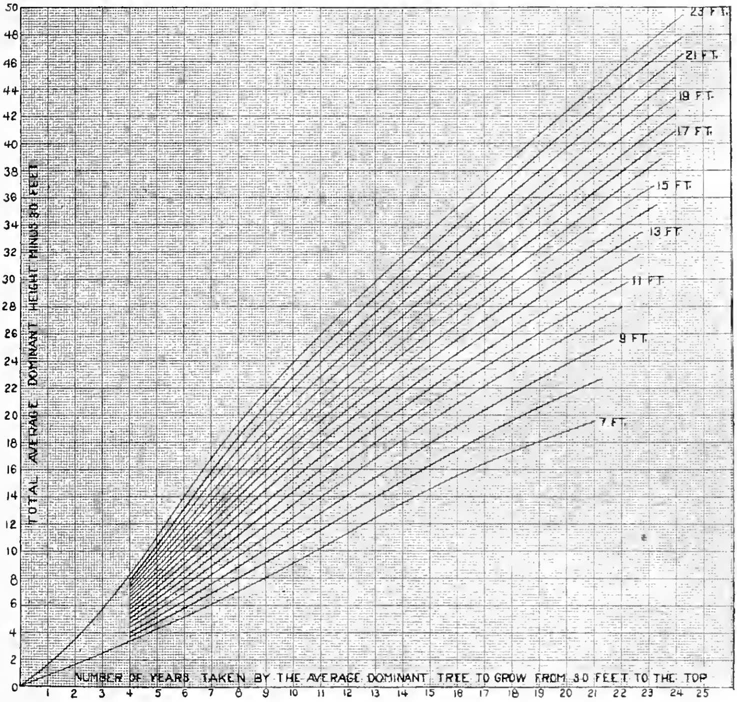

FIGURE 59. Site index curves for use when the exact total age is unknown. "Three-feet-to-the-top" method. Derived from Figure 58.

above ground either by increment borings or by counting internodes back from the tip. Apply the values thus secured to the curves. (Figure 59.)

The site index curves and table being constructed, the height-age data secured at each plot were converted into terms of site index for the purposes of correlation with the soil factors at that plot. A summary of the site indices of the 194 plots, all or part of which were used in the various correlations, follows:

Site index, feet	Number of plots	Percentage of total number of plots
7, 8, 9	2	1.03
10, 11	2	1.03
12, 13	2	1.03
14, 15	16	8.25
16, 17	54	27.80
18, 19	90	46.46
20, 21, 22	28	14.40
	194	100.00

Mean site index, 17.6 feet

The fact that almost all red pine plantations not subject to brush competition have been made on potential agricultural soil accounts for this skewed frequency distribution.

STATISTICAL AND GRAPHIC ANALYSIS

In the instances where 194 paired soil values and site indices were determined, analysis was made by means of correlation tables (which are more efficient instruments than scatter diagrams when the number of observations is so great) and derived figures. Scatter diagrams were added where there were only 58 observations, and scatter diagrams alone were used where there were only 25 observations. Column diagrams were used in several instances to bring out special features of correlation or lack of correlation.

The figures or diagrams showing a series of connected coördinates are derived from either correlation tables or scatter diagrams. Each coördinate is weighted with the number of plots that determined its location. Where correlation was evident from the departure of a series of coördinates from a horizontal line, a curve was fitted to the data and the index of correlation[1], the statistical measure of the extent of any correlation described by a curve (as opposed to a straight line), was computed. It may be explained briefly that the magnitude of the index of correlation depends on the difference between the standard deviation of the dependent variable about the fitted curve (the standard error of estimate) and the standard deviation about the mean of all the dependent variables. The dependent variable is the one plotted on the vertical scale in a graph; it is "site index" in most of the graphs in this study.

Relation Between Site Index and Various Soil Properties Observed in the Field

1. Soil series

In attempting to correlate site index with soil series, it is advisable to combine some of the series into larger groups, ignoring

[1] Mills, C. M. Statistical methods, 560. 1924.

the finer distinctions recognized in soils mapping. The present study warrants the use of six groups, as follows:

a. Upland soils, very well drained; brown surface on reddish-yellow brown, rather loose and open subsoil.
Series: Gloucester, Brookfield, Hinsdale, Maltby, Holyoke.

b. Upland soils with good drainage, grayish-brown surface on firm to compact, olive colored subsoil.
Series: Hollis, Charlton, Woodbridge, Bernardston.

c. Upland soils of central Connecticut within the area of red sandstone and shale rocks. Soils predominately red in color.
Series: Cheshire, Wethersfield.

d. Imperfectly drained upland soils.
Series: Peru.

e. Open leachy soils found on gravelly knolls and ridges.
Series: Hinckley, Manchester.

f. Sandy terrace soils, mostly level with no stones or boulders.
Series: Merrimac, Hartford.

The data shown in Table 19 indicate a slight correlation of soil groups with site index, varying from the more compact subsoil group to the open terrace soils, which are poorest in site quality. This is shown most clearly by the mean site index. The impracticability of attempting a correlation with individual soil series is at once apparent. Next to the Merrimac and Hartford series, the red sandstone groups are the poorest in site quality.

Table 19. The Relation of Soil Series to Site Index

Site index, feet	Charlton Hollis Woodbridge Bernardston	Gloucester Brookfield Hinsdale Maltby Holyoke	Peru	Hinckley Manchester	Cheshire Wethersfield	Merrimae Hartford	Totals
	Soil series						
	Number of plots						
7, 8, 9	..	..	..	..	..	2	2
10, 11	..	..	..	..	..	2	2
12, 13	..	..	..	..	..	2	2
14, 15	..	3	1	4	6	2	16
16, 17	12	10	1	6	21	3	53
18, 19	31	22	5	16	8	2	84
20, 21, 22	13	6	1	1	3	1	25
Totals	56	41	8	27	38	14	184
Mean site index, feet	18.5	18.0	18.0	17.5	16.9	14.1	17.6

2. Soil texture

It is generally conceded that moisture is one of the most limiting factors in forest tree growth and, since moisture is quite closely tied up with soil texture in that the heavier soils possess the greater moisture-holding capacity, a correlation with soil texture is attempted, ignoring series. The data are given in Table 20. The mean site index indicates some correlation, considerably better than in the case of the soil series relationship in the previous table.

Table 20. The Relation of Soil Texture to Site Index

Site index, feet	Loam to silt loam	Fine sandy loam	Sandy loam Loamy sand Sand Medium sand Gravelly sand	Totals
	Soil texture			
	Number of plots			
7, 8, 9	..	..	2	2
10, 11	..	..	1	1
12, 13	..	1	..	1
14, 15	..	8	3	11
16, 17	..	39	7	46
18, 19	13	48	5	66
20, 21, 22	2	18	1	21
Totals	15	114	19	148
Mean site index, feet	18.7	17.8	15.7	17.6

3. Character of subsoil

A third quality of the soil that often is the controlling factor in productive capacity is the character of the subsoil. Data compiled from field observation are given in Table 21. On the whole one must say that the subsoils of the plots studied have not, up to the present time, held a controlling influence in the growth of these red pines. As the trees become larger, the character of the subsoil may exert a greater influence.

TABLE 21. THE RELATION OF THE CHARACTER OF THE SUBSOIL TO SITE INDEX

Site index, feet	Character of subsoil				
	Shallow rocky	Compact	Firm	Loose	Totals
	Number of plots				
7, 8, 9	..	..	..	2	2
10, 11	..	..	..	1	1
12, 13	..	..	1	..	1
14, 15	..	3	6	2	11
16, 17	2	9	26	9	46
18, 19	6	13	32	15	66
20, 21, 22	3	3	12	3	21
Totals	11	28	77	32	148
Mean site index, feet	18.6	17.6	17.7	17.0	17.6

4. Character of the A_{0-1} horizon

Since most of the feeding roots of red pine are in the A_0 and A_1 layers the character of that portion of the forest soil profile is of considerable importance. Some of the forests of central Europe have deteriorated badly because of the failure of the silvicultural system practiced to maintain the forest humus in a good condition. A good earthworm mull is desirable under average conditions as being most favorable to growth, while a raw humus condition is unfavorable, with the intermediate types coming in between.

In data recorded in Table 22 a correlation is present, though slight in degree. Again, as the trees grow older, this factor will probably assume increasing importance in influencing growth.

Table 22. The Relation of the Structure of the A_{0-1} Horizon to Site Index

Site index, feet	Good earthworm mull	Fair mull; fair to poor earthworm activity	No mull; no earthworm activity	Raw humus	Totals
	Character of the A_{0-1} horizon				
	Number of plots				
7, 8, 9	..	..	1	1	2
10, 11	..	..	..	1	1
12, 13	..	..	1	..	1
14, 15	1	7	2	1	11
16, 17	16	21	7	2	46
18, 19	34	22	8	2	66
20, 21, 22	10	10	1	0	21
Totals	61	60	20	7	148
Mean site index, feet	18.3	17.7	16.8	14.7	17.6

5. Soil reaction

The reaction of the A horizon and in some cases the B horizon of most of the profiles examined was determined in the field, using the Lamotte-Morgan soil testing kit. No correlation could be found, however, so none of the data is given.

The Relation Between Site Index and Silt-Plus-Clay and Colloidal Content of the A_{1-2} Horizon

Silt-plus-clay content and colloidal content of the A_{1-2} horizon were determined by the rapid method developed by Bouyoucos.[1] Both are measures of the proportions of very fine particles in the soil, the former including all particles 0.05 mm. and less in diameter (the upper limit of the silt fraction), the latter including all particles 0.005 mm. and less in diameter (the upper limit of the clay fraction) and a small, variable part of the silt fraction. The value for colloidal content obtained by this method is, therefore, only an approximation of the true clay content, which is, of course, somewhat lower. The colloidal content is widely recognized by soil investigators as being a very important factor influencing moisture-holding capacity, base exchange, absorption and general soil tilth.

[1] Bouyoucos, G. J. The hydrometer as a new and rapid method for determining the colloidal content of soils. Soil Science, 23: 319-331. 1927.
Bouyoucos, G. J. Making mechanical analyses of soils in fifteen minutes. Jour. Amer. Soc. Agron., 20: 305-306. 1927.

The determination of the relationship between these two soil factors and the site index of the red pine plantations was a virtual repetition of the major part of Haig's work, the repetition being made because Haig's site indices were based on anamorphosis of a single graduating curve by Reineke's[1] modification of Bruce's method. As indicated in the section on site quality, this method was found to produce inaccurate results when applied in young red pine plantations. Except for the difference in the character of the site index curves and the fact that it was possible to extend both the number and the geographical range of the plots, Haig's and the present study are entirely comparable.

Haig found that the relationship of both silt-plus-clay content and colloidal content to site index could be described by a curve showing that "soils of low colloidal content are relatively less productive, that as the colloidal or silt-plus-clay content increases the site quality increases also until certain optimum conditions are reached, and that beyond this point site quality falls off steadily with any further increase in colloidal material." He found the curve for colloidal content to have a correlation index of 0.52 ± 0.07 and the curve for silt-plus-clay content to have a correlation index of 0.58 ± 0.07. The former curve attained a broad peak (i.e., indicated the highest site index) at about 17 to 20 per cent colloidal content; the latter curve attained a broad peak at about 40 to 45 per cent silt-plus-clay.

TABLE 23. THE RELATION BETWEEN SILT-PLUS-CLAY CONTENT OF THE A_{1-2} HORIZON AND SITE INDEX

Site index, feet	Silt-plus-clay content, per cent 16—20	21—25	26—30	31—35	36—40	41—45	46—50	51—55	56—60	61—65	66—70	Totals	Mean silt-plus-clay content, per cent
	Number of plots												
7, 8, 9	2	..	..	..	..	..	..	..	..	..	..	2	18
10, 11	2	..	..	..	..	..	..	..	..	..	..	2	18
12, 13	2	..	..	..	..	..	..	..	..	..	..	2	18
14, 15	..	2	..	3	3	4	..	3	1	..	..	16	40
16, 17	..	4	3	8	10	10	7	4	2	5	1	54	43
18, 19	..	3	4	15	14	17	14	13	6	3	1	90	43
20, 21, 22	..	1	2	3	5	1	5	7	4	..	..	28	45
Totals	6	10	9	29	32	32	26	27	13	8	2	194	..
Mean site index, feet	10.5	17.1	18.3	17.7	17.8	17.4	18.3	18.3	18.5	17.2	17.5	17.6	

[1] Reineke, L. H. A modification of Bruce's method of preparing timber yield tables. Jour. Agr. Research, 35: 843-855. 1927.

In the present study, however, silt-plus-clay content shows no correlation with site index beyond 20 to 25 per cent (see Figure 60 and Table 23) and colloidal content shows only a very slight correlation. It is clearly evident in Figure 60 that there is a strong positive correlation between site index and silt-plus-clay contents of 25 to 30 per cent and less. Further, it appears that, excluding the group of 6 plots having a silt-plus-clay content of 15 to 20

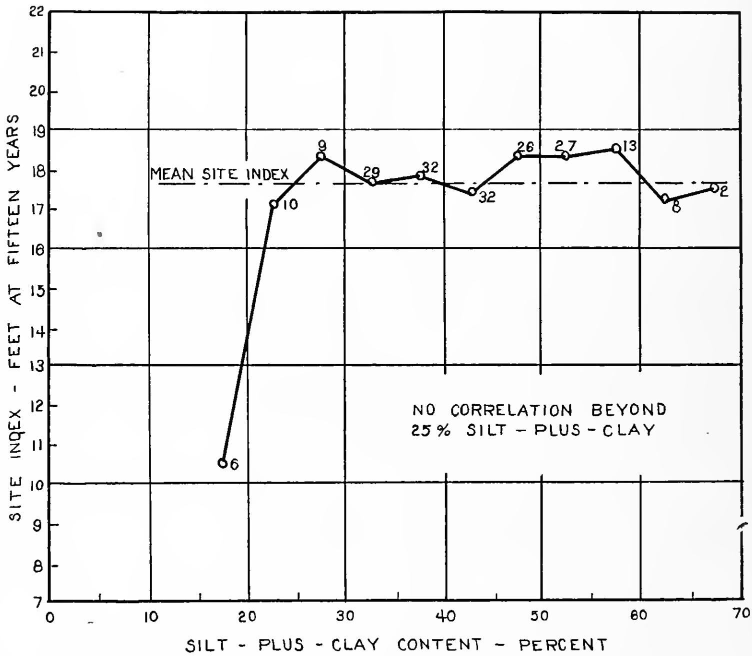

FIGURE 60. The relation of site index to the silt-plus-clay content of the A_{1-2} horizon. Basis, 194 plots.

per cent, the remaining 10 groups—from 20-25 to 65-70 per cent—show no correlation whatever. This lack of correlation is shown even more strikingly in Table 23. The correlation index for all of the 194 plots would be so slightly above zero as to be meaningless and, therefore, was not computed. There is an unaccountable peak between 25 and 30 per cent, and an unaccountable depression between 40 and 45 per cent where Haig's averages and curve are highest. Incidentally, Haig's group averages are actually somewhat depressed between 30 and 40 per cent. There is, of course, no justification for making a curve with two distinct peaks between which is an equally distinct depression. The suggestion or indication of such a curve in Figure 60 really serves to

emphasize the lack of correlation. There is a second depression, beyond 60 per cent silt-plus-clay, which substantiates Haig's finding that beyond a certain point further increase in silt-plus-clay content is accompanied by a decrease in site index. There is, however, no agreement between the two sets of data on the location of that point. Figure 61, which is self-explanatory, presents the data of Figure 60 and Table 23 in somewhat different form.

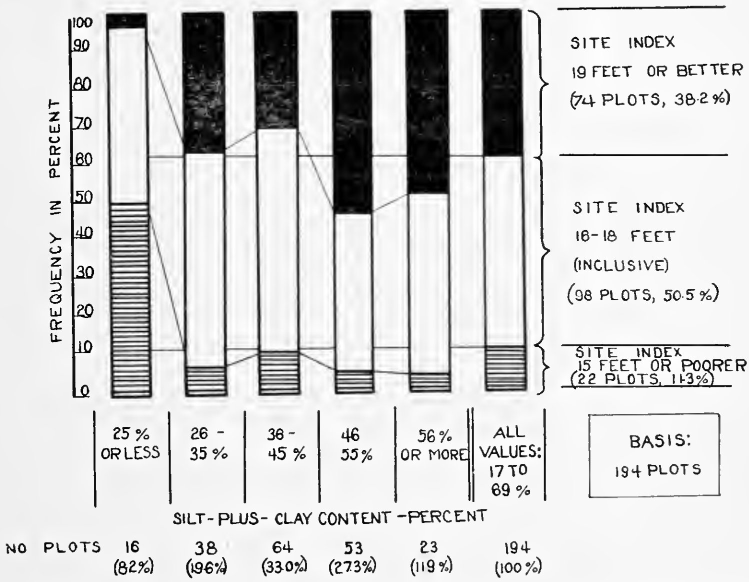

FIGURE 61. Frequency distribution of three site index classes by silt-plus-clay classes.

Colloidal content, as measured by the Bouyoucos method, showed no apparent correlation with site index except that the average of site indices for all soils with a colloidal content below 15 per cent was significantly below the mean. The general character of the data was similar to that for silt-plus-clay content, hence the results need not be presented. Haig had also found a poorer correlation with colloidal content than for silt-plus-clay content.

The Relation Between Site Index and Moisture Equivalent of the A_{1-2} Horizon

The moisture equivalent of a soil is defined as the percentage of water retained against a constant centrifugal force usually taken

as 1,000 times the force of gravity. In general, the finer the soil and the greater the organic content the greater the moisture equivalent. Briggs and McLane[1] state that "The moisture equivalent represents the amount of moisture content which each soil must have in order to make it equally difficult to remove a very small additional amount of moisture from any of the soils. It is from

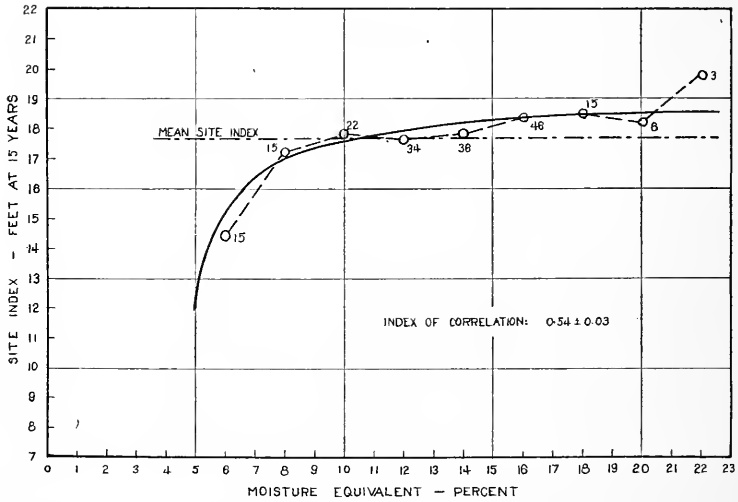

FIGURE 62. The relation of site index to moisture equivalent of the A_{1-2} horizon. Basis, 194 plots.

this point of view that the moisture equivalent becomes of special importance in the comparison of the moisture content of different soils under growing trees." Briggs and Shantz[2] working with agricultural soils found a constant relationship between the wilting coefficient and the moisture equivalent, described by the following equation:

$$\text{wilting coefficient} = \frac{\text{moisture equivalent}}{1.84\ (1 \pm 0.007)}$$

In this study, the moisture equivalent of the A_{1-2} horizon was determined by the method described by Briggs and McLane[1] except that oven-dried (at 105° C.), not air-dried, samples were used. The use of oven-dried samples generally results in slightly

[1] Briggs, L. J., and McLane, J. W. The moisture equivalent of soils. U. S. Bur. of Soils, Bull. 45. 1907.

[2] Briggs, L. J., and Shantz, H. L. The wilting coefficient for different plants and its indirect determination. U. S. Bur. Plant Ind., Bull. 230. 1912.

lower moisture equivalent values than are obtained from air-dried samples.

In Figure 62 it will be seen that there is a definite positive correlation between moisture equivalent and site index, that this correlation can be described by a curve of the logarithmic type, and that the extent or degree of correlation expressed by this curve is fairly high as shown by the index of correlation of 0.54 ± 03. Table 24 presents the data in tabular form.

TABLE 24. THE RELATION BETWEEN MOISTURE EQUIVALENT OF THE A_{1-2} HORIZON AND SITE INDEX

Site index, feet	Moisture equivalent, per cent									Totals	Mean moisture equivalent per cent
	5.0—6.9	7.0—8.9	9.0—10.9	11.0—12.9	13.0—14.9	15.0—16.9	17.0—18.9	19.0—20.9	21.0—22.9		
	Number of plots										
7, 8, 9	2	..	..	..	..	..	..	..	..	2	6.0
10, 11	2	..	..	..	..	..	..	..	..	2	6.0
12, 13	2	..	..	..	..	..	..	..	..	2	6.0
14, 15	2	2	4	4	2	2	..	..	..	16	11.0
16, 17	4	8	4	10	14	10	2	2	..	54	12.6
18, 19	2	3	10	17	15	25	12	5	1	90	14.3
20, 21, 22	1	2	4	3	5	9	1	1	2	28	14.1
Totals	15	15	22	34	36	46	15	8	3	194	
Mean site index, feet	14.4	17.2	17.8	17.6	17.8	18.3	18.4	18.2	19.8	17.6	

Figure 63 presents the same data in a different form. Here it is shown very clearly that the proportion of good sites increases constantly and quite uniformly, and that the proportion of poor sites decreases in a similar way, with increase in moisture equivalent. The figure brings out many facts of interest that are not shown as well, if at all, in Figure 62 or Table 24. To obtain the best picture of the correlation between moisture equivalent and site index both figures and the table should be examined carefully and compared.

The Relation Between Site Index and the Total Nitrogen Content of the A_{1-2} Horizon

For the purposes of this study only 58 plots out of 194 were used. They were selected so that there would be as far as possible a preponderance of good and poor sites and a minimum of average sites because in this way it was hoped that any correlation which might exist would be indicated with the minimum number of total nitrogen analyses. Within the several site index groups, plots

were selected at random from as many different soil classes and as many different plantations as possible.

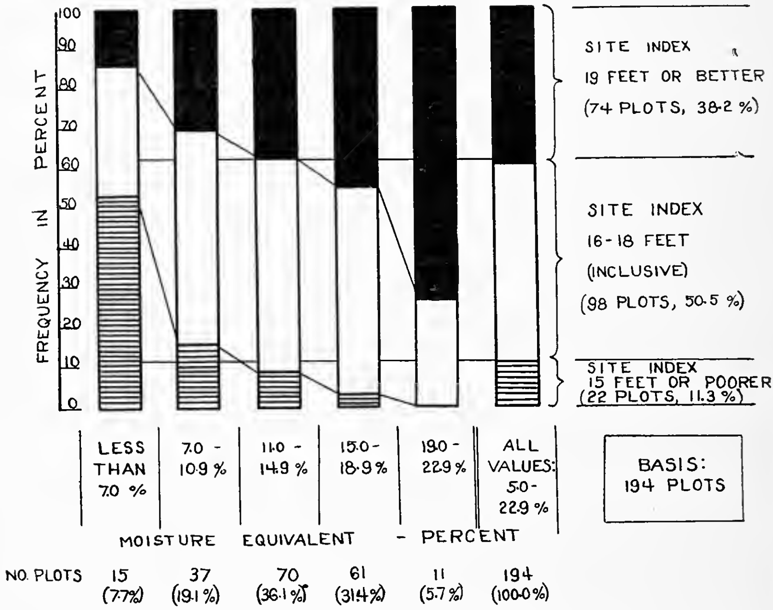

FIGURE 63. Frequency distribution of three site index classes by moisture equivalent classes.

A summary of the site indices of the 58 plots selected follows:

Site index, feet	Number of plots	Percentage of total number of plots
7, 8, 9	2	3.45
10, 11	1	1.72
12, 13	..	....
14, 15	14	24.15
16, 17	13	22.40
18, 19	7	12.08
20, 21, 22	21	36.20
	58	100.00

Mean site index, 17.5 feet

Nitrogen is one of eight important elements essential to normal plant growth and reproduction. Of the total quantity of nitrogen present in any soil, however, only the nitrogen in ammonia and nitrates is ordinarily available to non-leguminous plants. Both ammonia and nitrates are products of the breakdown of nitrogenous complexes in the soil, the process being known as nitrogen

transformation or mobilization. At any given time that a soil is analyzed usually only a small fraction of the total nitrogen content is present in available form. Under favorable conditions, however, the total nitrogen content is drawn upon for the liberation of more ammonia which, depending again on the presence of favorable conditions, is partially or wholly converted into nitrates. During the growing season, when by far the greater part of such nitrogen transformation takes place, the products are generally used as rapidly as they are produced so that there is no great accumulation of either ammonia or nitrates in the soil. It is usually true that the more total nitrogen in a soil the greater the potential available nitrogen.

The total nitrogen content of the A_{1-2} horizon was determined by the Kjeldahl method which, although it does not account for all the nitrate nitrogen, gave correct values for the soil, analyzed because nitrates were either not present at all or at best present only to the extent of 3 or 4 parts per million.

A number of European investigators have found that total nitrogen content and nitrogen transformation are very important factors in the growth of forest trees. Cajander,[1] in reviewing various studies of site quality in relation to the chemical composition of the soil, shows that von Falckenstein found a striking positive correlation between the nitrogen content of a surface layer 23.6 inches in depth and "the quality class" or yield capacity of the forest on sandy lands in northern Germany. The higher the quality class the greater was the total nitrogen content. Cajander also shows that Ilvessalo, working with soil analyses made by Valmari, found that the coefficient of correlation between the growth of normally developed Scots pine stands and the total nitrogen content of the soil for forest land in southern Finland was 0.736 ± 0.056. There was a slightly lower coefficient for lime content. In this connection, Hesselman[2] has pointed out that lime and nitrogen in combination signify good nitrogen transformation, which he considers one of the most important factors influencing the growth of stands. Nemec and Kvapil,[3] Valmari[4] and Aaltonen[5]

[1] Cajander, A. K. The theory of forest types. Helsinki. 1926.

[2] Hesselman, H. Studies of the humus layers of coniferous forests. their peculiarities and their dependence on silviculture. Translation by P. R. Gast of the German resume in Meddelanden fran Statens Skogsförsökanstalt, Hafte, 22, Nr. 5, 169-552. 1926.

[3] Nemec, A., and Kvapil, K. Studien über einige chemische Eigenschaften der Profile von Waldböden. Zeit. für Forst u. Jagd. 59:321-352, 385-412. 1926.

[4] Valmari, J. Beitrage zur chemischen Bodenanalyse. Acta forestalia fennica, 20. Helsingfors. 1921.

[5] Aaltonen, V. T. Uber die Umsetzungen der Stickstoffverbindungen im Waldböden. (Summary: Decomposition of nitrogenous compounds in woodland soils). Comm. Inst. Quaest. Forest. Finland. Ed. 10., Helsinki. 1926.

have all found that total nitrogen content increases with increase in "quality-class" or yield capacity of forest types.

In the present study, Figure 64 shows that there is a fairly good positive correlation between total nitrogen content and site index. The correlation can be described by a curve of the same general

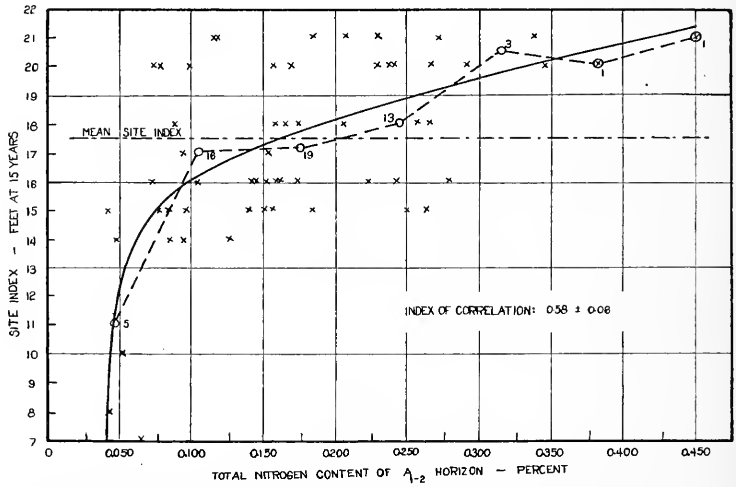

FIGURE 64. The relation of site index to total nitrogen content of the A_{1-2} horizon. Basis, 58 plots.

type as that describing the correlation between moisture equivalent and site index. In the present case, however, the curve is much steeper and the index of correlation, 0.58 ± 0.06, is somewhat higher. There is good reason to believe that if more samples of average site indices had been included the index of correlation would be still higher and the probable error would be much smaller.

TABLE 25. THE RELATION BETWEEN TOTAL NITROGEN CONTENT OF THE A_{1-2} HORIZON AND SITE INDEX

Site index, feet	Total nitrogen content, per cent 0—0.070	0.071—0.140	0.141—0.210	0.211—0.280	0.281—0.350	0.351—0.420	0.421—0.490	Totals	Mean total nitrogen content per cent
	Number of plots								
7, 8, 9, 10	3	..	..	..	..	..	..	3	0.052
11, 12, 13	..	..	..	..	..	..	..	..	....
14, 15, 16	2	9	9	5	..	..	..	25	0.153
17, 18, 19	..	2	5	2	..	..	..	9	0.175
20, 21, 22	..	5	5	6	3	1	1	21	0.222
Totals	5	16	19	13	3	1	1	58	
Mean site index, feet,	11.1	17.1	17.2	18.0	20.5	20.5	20.5	17.5	

Table 25 shows the correlation in condensed form. Since the 28 samples of poor site indices (16 feet and less) represent 57 per cent of all such plots found and the 21 samples of good site indices (20 feet and more) represent 75 per cent of all such plots found, whereas the nine samples of average site indices (17 to 19 feet) represent less than 8 per cent of all such plots found, the distribution of the first two groups, the poor site indices and the good site indices, gives a good picture of the extent of correlation to which the inclusion of the third group (the average site indices) adds little or nothing.

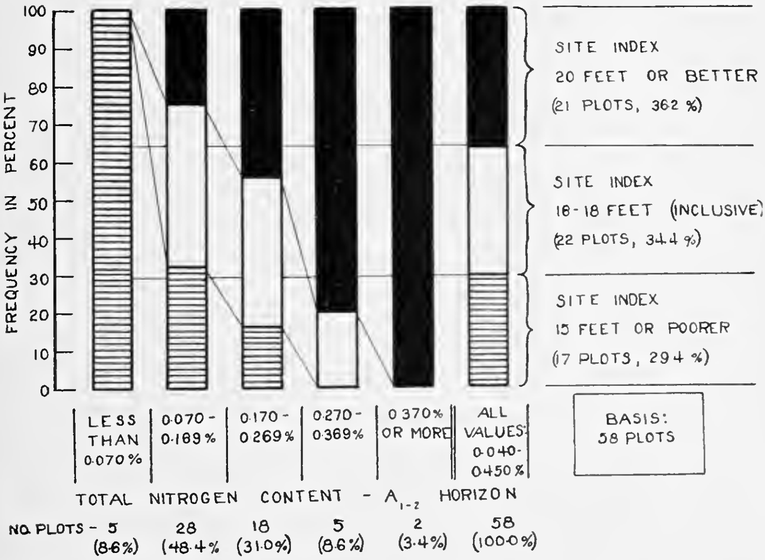

FIGURE 65. Frequency distribution of three site index classes by total nitrogen classes.

Figure 65 shows strikingly that the percentage of good site indices increases from zero to 100 per cent and that the percentage of poor site indices decreases from 100 per cent to zero with increase in total nitrogen content. The significance of the figure is somewhat weakened by the small number of samples of extreme nitrogen contents. However, although the use of more such samples would probably make the correlation slightly less clear-cut to the casual glance, the addition would probably actually strengthen the statistical measure of correlation.

Since both moisture equivalent and total nitrogen content are correlated in the same way and to comparable degrees with site index it is of interest to see how these two soil factors are corre-

lated with one another. Their correlation is shown in Figure 66. It is of the same general type exhibited by each factor with site index, yet approaches much more closely a straight line correlation. Nothing is gained by calculating the exact index of correlation but merely by inspection it appears considerably higher than for either of the two factors with site index. By distinguishing between the coördinates derived from three arbitrary site classes—good (20 feet or more), medium (17 to 19 feet), and poor (16 feet or less), an interesting fact is brought out. The coördinates representing the good sites tend to be concentrated to the right (horizontally,

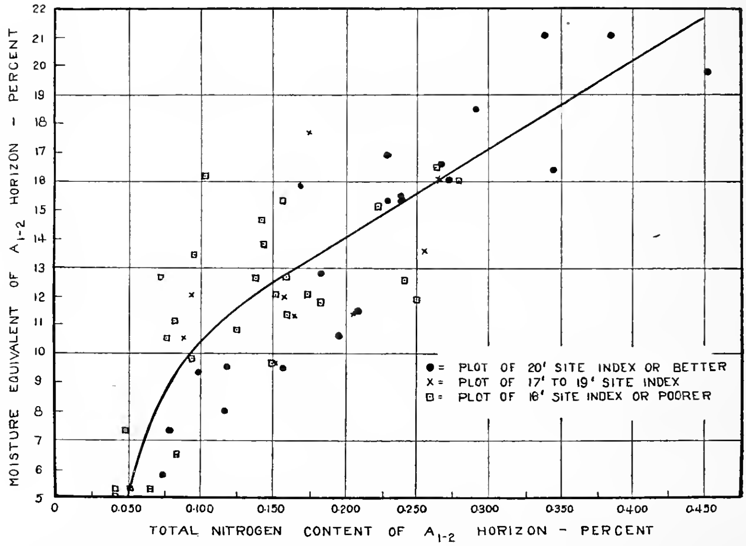

FIGURE 66. The relation of moisture equivalent to total nitrogen in the A_{1-2} horizon. Basis, 58 plots.

not diagonally) of those representing the poor sites. This is equivalent to stating that for a given moisture equivalent the poor site indices occur most commonly where the total nitrogen content is relatively low (for that particular moisture equivalent) and the good site indices occur most commonly where the total nitrogen content is relatively high.

From this it would seem that, although total nitrogen content and moisture equivalent are definitely and positively correlated with one another, and with site index to about the same degree, it is the total nitrogen content that is the more fundamenally correlated with site index, whereas the moisture equivalent owes its correlation with site index to its correlation with total nitrogen content to a considerable extent.

Nitrogen Transformation of the Duff and Humus-Rich Mineral Horizons under Red Pine Plantations of Varying Site Indices

The total nitrogen content of the organic material in forest soils is largely in the form of proteins or complex protein-derivatives. Under favorable conditions of temperature, moisture and aeration these organic nitrogenous substances are partially transformed into ammonia and nitrate nitrogen. This mobilization of nitrogen is accomplished through the activities of certain micro-organisms in the soil.

At the same time the entire microflora of the soil are capable of synthesizing these simpler nitrogen compounds into the proteins necessary for their own living cells. When large amounts of non-nitrogenous organic compounds, such as sugars, hemi-celluloses and celluloses are present in the organic material, the micro-organisms that are actively decomposing these substances rapidly consume any available nitrogen that may be present.[1]

The amounts of ammonia and nitrate nitrogen that are present in the soil at any time are dependent upon:

1. The total amount and character of the organic nitrogen in the soil.
2. The environmental factors (such as temperature, moisture, aeration, soil reaction) favorable and unfavorable to nitrogen transformation.
3. The consumption of transformed nitrogen by the soil population.
4. The intake of ammonia and nitrate nitrogen by plant roots.

With such a wide range of variables, it is obvious that a simple determination of the nitrate or ammonia contents of the various soil horizons at any one time as they exist in the forest would be of little value.

In agronomic research the amounts of these forms of nitrogen that are produced in the soil as a result of incubation for a definite period under constant and favorable conditions of temperature and moisture have long been used by a number of investigators as a standard for evaluating the availability of the nitrogen in the soil.

In more recent years this method has been applied to forest soils, chiefly by such European investigators as Hesselman,[2] Ilvessalo,[3]

[1] More complete discussions of these processes are presented by Waksman in Principles of Soil Microbiology, published by the Williams and Wilkins Co.

[2] Hesselman, H. Studies of the humus layers of coniferous forests, their peculiarities and their dependence upon silviculture. Meddalanden gran Statens Skogsförsöksanstalt, 22: 169-552. 1926.

[3] Ilvessalo, Y. Vegetations statistische Untersuchungen über die Waldtypen. Acta forestalia fennica, 20. Helsinki. 1923

Aaltonen,[1] Nemec and Kvapil[2] and Clarke.[3] Since the amount of available nitrogen is obviously an important growth factor, it seemed desirable to apply this method of investigation to a number of the soils included in the red pine plantation study.

During the fall of 1928 samples were collected from 14 of the sample plots used in other phases of the red pine project. These plots were chosen as representing seven pairs of plots, one showing a somewhat better site index than the other, although only a short distance apart (not more than 300 feet) and representing the same soil type and past history. These plots are numbered so that "a" represents the better and "b" the poorer plot in each pair. Although the various pairs of plots represent a considerable range in site index, there is no wide difference between the two plots of any pair. The pairs were chosen on the basis of preliminary data that showed wider differences between the two paired plots than later proved to be the case.

The character of the humus-rich mineral soil horizon (A_{1-2}) of this group of plots is indicated by Table 26, which also gives the red pine site index figures.

TABLE 26. MISCELLANEOUS DATA, 1928 SERIES OF NITROGEN TRANSFORMATION PLOTS

					A_{1-2} Horizon (upper 4-5 in. of mineral soil)				
Plot No.	Location	Soil type	Age of plantation years	Site index feet	Total nitrogen content per cent	Moisture equivalent per cent	Silt-plus-clay content per cent	Bouyoucas colloidal content per cent	pH
1a	Rainbow	Merrimac coarse sand ..	31	10	0.082	5.3	19	12	4.
1b	Rainbow	Merrimac coarse sand ..	31	8	0.059	5.3	17	10	4.
2a	Rainbow	Merrimac coarse sand ..	17	13	0.081	6.0	18	11	4.
2b	Rainbow	Merrimac coarse sand ..	17	11	0.080	5.5	19	11	4.
		average of 4 very sandy soils		10.5	0.076	5.5	18	11	4.
3a	Middlebury	Brookfield f. s. l.	18	19	0.167	12.3	32	15	4.
3b	Middlebury	Brookfield f. s. l.	18	18	0.271	15.9	36	14	4.
4a	Middlebury	Charlton loam	18	20	0.169	13.9	42	23	4.
4b	Middlebury	Charlton loam	18	17	0.213	15.1	40	24	4.
5a	Bethany	Charlton loam	17	19	0.249	14.8	43	21	4.
5b	Bethany	Charlton loam	17	16	0.305	16.0	40	23	5.
6a	Bethany	Gloucester f. s. l.	18	19	0.290	13.0	37	16	4.
6b	Bethany	Gloucester f. s. l.	18	18	0.225	11.4	35	17	4
7a	Prospect	Brookfield f. s. l.	17	21	0.142	9.6	35	19	4
7b	Prospect	Brookfield f. s. l.	17	19	0.181	9.4	30	17	4
		average of 10 loam and f. s. l. soils		18.6	0.221	13.1	37	19	4

[1] Aaltonen, V. T. Uber die Umsetzungen des Stickstoffverbindungen im Waldböden. Comm. Inst. Quaest. Forest, Finland, Ed. 10, Helsinki. 1926.

[2] Nemec, A., and Kvapil, K. Uber die Einflusse verschiedener Waldbestande auf den Gehalt und die Bildung von Nitraten im Waldböden. Zeit. fur Forst u. Jagd., 59: 321-352, 385-412. 1927.

[3] Clarke, G. R. Soil acidity and its relation to the production of nitrate and ammonia in woodland soils. Oxford Forestry Memoir No. 2. 1924.

It is evident from the table that there are only slight differences in the paired soils, while the inferior quality of four very sandy soils from the Rainbow plantation is reflected in the consistently low site index of this group.

The samples of both the duff (A_0 or "F" layer) and the A_{1-2} horizon were collected in October and stored in muslin sacks in an open shed until December, when they were mixed, pulverized and prepared for incubation and laboratory analyses.

The incubated samples were made up to optimum moisture content, and stored for a period of 3 months in the basement of the laboratory where the temperature averaged approximately 25° C. Ammonia and nitrate nitrogen were determined both at the beginning and at the end of the incubation period.

The data obtained from the seven pairs of samples collected in the fall of 1928 are presented in Table 27. Samples of the A_0 horizon (duff) were not collected for numbers 2 and 7.

TABLE 27. AMMONIA AND NITRATE NITROGEN DATA, 1928 NITROGEN TRANSFORMATION SERIES

Plot No.	Site index, feet	Duff (A_0 or "F" layer) Nitrogen transformation in 3 months: Ammonia nitrogen p. p. m.	Duff: Nitrate nitrogen p. p. m.	Duff: Total p. p. m.	Duff: Total nitrogen in original soil, per cent	A_{1-2} Horizon (upper 4-5 in. of mineral soil) Nitrogen transformation in 3 months: Ammonia nitrogen p. p. m.	A_{1-2}: Nitrate nitrogen p. p. m.	A_{1-2}: Total p. p. m.	A_{1-2}: Total nitrogen in original soil, per cent
1a	10	466	4	470	1.360	15	trace	15	0.082
1b	8	541	4	545	1.073	17	trace	17	0.059
2a	13	not determined				14	14	28	0.081
2b	11	not determined				22	trace	22	0.080
3a	19	2,129	4	2,133	1.449	82	5	87	0.167
3b	18	1,585	1,214	2,799	1.501	73	59	132	0.271
4a	20	586	1,261	1,847	1.182	11	90	101	0.169
4b	17	677	911	1,588	1.175	57	55	112	0.213
5a	19	700	495	1,195	1.222	40	69	109	0.249
5b	16	827	4	831	1.102	45	91	136	0.305
6a	19	1,900	5	1,905	1.373	55	15	70	0.290
6b	18	1,535	5	1,543	1.219	79	8	87	0.225
7a	17	not determined				44	2	46	0.142
7b	17	not determined				37	10	47	0.181

The A_0 horizon transforms a much larger total amount of nitrogen than for the A_{1-2} horizon, on the basis of the dry weight of the material. This is to be expected, on the basis of the much higher nitrogen content of this layer. However, a larger proportion of the total nitrogen content of the original soil becomes available in the A_{1-2} horizon.

The formation of nitrate nitrogen is extremely variable, especially in the A_0 horizon. There is a tendency for the soils in each horizon with the highest total nitrogen content to liberate the

greatest amount of nitrate nitrogen, although there are conspicuous exceptions.

The much lower nitrogen transformation of the coarse sandy soils from Rainbow (Plots 1a to 4b inclusive) is consistent, and suggests a possibility that the low site index on these plots may be due in part to the lack of available nitrogen on these soils. The total nitrogen transformation on all the other plots represents an amount of available nitrogen that should be adequate to meet the possible requirements of tree growth in all cases. Thus with an average weight of dry duff material of approximately 15,000 pounds per acre, the minimum amount of nitrogen transformation in 3 months (831 p.p.m. for plot 5b) represents approximately 13 pounds of available nitrogen per acre, and with 4 inches of A_{1-2} horizon weighing approximately 1,200,000 pounds per acre, the minimum (46 p.p.m. for plot 7a) gives 55 pounds of available nitrogen, or a total for these two horizons of 68 pounds of combined ammonia and nitrate nitrogen as a minimum for the loam and fine sandy loam soil group. It is not surprising that the data revealed no correlation between site index and nitrogen transformation, either in the A_0 or A_{1-2} horizon in such soils.

Nitrogen Transformation Studies in 1929 for the Duff Layer from Twenty-Five Selected Plots

Since the samples used in 1928 represented only the very low and the good to excellent site index groups, it was considered desirable to select from the entire list of sample plots a group of 25 that was representative of four different degrees of site quality. Four plots have site indices of 10 feet or less; eight plots, of 14 to 16 feet; six plots, of 18 feet; and seven plots, of 21 to 22 feet. Only the A_0 (duff) horizon from these plots was collected, since this layer showed the most significant degree of nitrogen transformation in the 1928 results.

The general characteristics of the A_{1-2} horizon occurring on these plots are indicated in Table 28.

TABLE 28. MISCELLANEOUS DATA FOR A_{1-2} HORIZONS ON PLOTS USED IN 1929 NITROGEN TRANSFORMATION STUDY

Plot No.	Location of plantation	Total age of plantation when litter was collected, years	Site index, feet	A_{1-2} Horizon: Silt-plus-clay content, per cent	A_{1-2} Horizon: Colloidal (clay) content, per cent	A_{1-2} Horizon: Moisture equivalent, per cent	A_{1-2} Horizon: Total nitrogen content, per cent
1	Rainbow	32	7	18	11	5.3	0.065
2	Rainbow	32	8+	17	10	5.3	0.042
3	Rainbow	32	10—	18	11	5.3	....
4	Rainbow	32	10+	19	12	5.3	0.051
5	Bridgeport	16	14	32	13	10.8	0.125
6	Lake Dawson	18	15—	55	23	16.5	0.264
7	Storrs campus	31	15	41	17	11.8	0.182
8	Lake Saltonstall	18	15+	51	13	13.4	0.095
9	Lake Wepawaug	18	15+	40	17	11.9	0.250
10	Lake Wintergreen	18	16—	40	22	12.1	0.151
11	Bridgewater	18	16	40	21	13.8	0.144
12	Middlebury	19	16	32	17	14.7	0.142
13	Middlebury	19	18—	34	18	17.7	0.174
14	Middlebury	19	18—	36	20	12.0	0.157
15	Lake Dawson	18	18—	42	19	13.6	0.256
16	Lake Saltonstall	18	18—	45	23	10.6	0.089
17	Lake Chamberlain	18	18—	51	22	16.1	0.265
18	Lake Wepawaug	18	18—	35	20	11.3	0.165
19	Racebrook	18	21—	52	26	16.9	0.228
20	Lake Chamberlain	19	21—	56	24	16.1	0.273
21	Middlebury	19	21—	49	22	19.8	0.451
22	Bantam	21	21—	36	15	12.8	0.183
23	Pomfret	17	21	52	15	11.5	0.207
24	Wolcott	18	21	35	15	8.0	0.116
25	South Coventry	18	22+	37	10	10.6	0.195

The A_0 samples from this series of plots were collected in October, 1929, brought into a heated room, spread out in open boxes and thoroughly air-dried. Although it was realized that this treatment would not give quite the same results as were obtained upon undried soils used the previous year, it was thought that more uniform conditions for each sample would be obtained. There was a considerable variation in the moisture content in the samples used in 1928 before they were more fully moistened just prior to incubation.

The samples were pulverized, moistened to approximately two-thirds saturation, and incubated for 3 months in the same manner as was used the preceding year. The results of ammonia and nitrate nitrogen determinations before and after incubation are presented in Table 29.

A conspicuous feature of the 1929 results was the lower general level of nitrate and ammonia content at the end of the 3 months'

TABLE 29. AMMONIA AND NITRATE NITROGEN DATA, 1929 NITROGEN TRANSFORMATION SERIES

Plot No.	Site index, feet	Ammonia nitrogen p. p. m. Before incubation	After 3 months incubation	Gain (+) or loss (—)	Nitrate nitrogen after 3 months incubation (none before), p. p. m.	Total of ammonia and nitrate nitrogen after 3 months incubation p. p. m.	Net nitrogen transformation p. p. m. Gain (+) or Loss (—)	Total nitrogen content, per cent
1	7	16	11	—5	0	11	—5	0.839
2	8	12	0	—12	0	0	—12	0.747
3	10—	24	0	—24	0	0	—24	0.840
4	10+	21	0	—21	0	0	—21	0.737
5	14	45	13	—32	0	13	—32	0.964
6	15—	67	338	+271	trace	338	+271	1.132
7	15	65	0	—65	0	0	—65	1.056
8	15+	33	0	—33	0	0	—33	0.679
9	15+	27	8	—19	0	8	—19	0.766
10	16—	44	122	+78	0	122	+78	1.056
11	16	40	353	+313	trace	353	+313	1.083
12	16	76	1,127	+1,051	12	1,139	+1,063	1.317
13	18—	81	703	+622	563	1,266	+1,185	1.385
14	18—	37	578	+541	trace	578	+541	1.111
15	18—	43	22	—21	0	22	—21	0.942
16	18—	36	77	+51	0	77	+51	0.919
17	18—	33	802	+769	trace	802	+769	1.277
18	18—	70	405	+335	trace	405	+335	1.137
19	21—	43	360	+317	208	568	+525	1.049
20	21—	65	227	+162	9	236	+171	1.044
21	21—	63	72	+9	20	92	+29	1.015
22	21—	72	1,563	+1,491	16	1,579	+1,507	1.338
23	21	12	15	+3	trace	15	+3	0.940
24	21	27	32	+5	trace	32	+5	0.936
25	22+	53	53	00	432	485	+432	1.005

incubation period than had been found for the 1928 samples. In fact, 5 of the 25 samples showed a complete disappearance of these forms of nitrogen as a result of incubation, while 3 others showed a decrease. This difference is undoubtedly due to the effect of air-drying the 1929 samples prior to their being prepared for incubation. The samples that showed a disappearance or decrease in combined nitrates and ammonia, or that showed a low net increase during the incubation period, all have a low total nitrogen content, as compared with the other samples which show a significant nitrogen transformation. In other words, the ratio of nitrogen to organic carbon is wider for the soils that fail to show an increase in available nitrogen.

The 1928 samples, which were not air-dried, suffered no marked disturbance in their biological activities. The non-nitrogenous organic matter was being decomposed in the field, and there was no complete cessation of this decomposition, as was the case for the

air-dried samples of 1929. Hence incubation merely produced a general acceleration of all biological activities as a result of more favorable temperature and moisture conditions.

If there is a greater acceleration of the activities of micro-organisms producing organic matter decomposition as a result of the restoration of moisture to the air-dried samples, than occurs in the undried samples, the consumption of ammonia and nitrates is correspondingly augmented, and only the nitrogen-rich material is

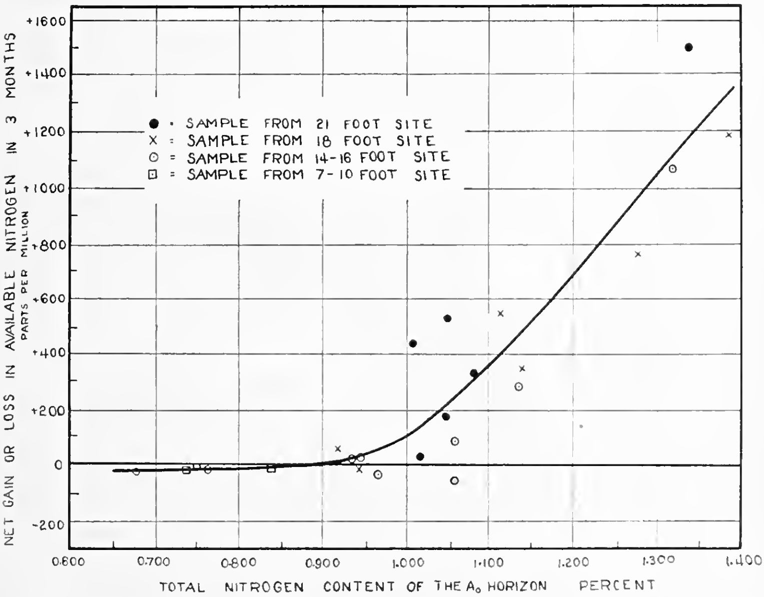

FIGURE 67. The relation of the total nitrogen content of the A horizon to the changes in available nitrogen (both ammonia and nitrates) during three months of incubation.

capable of producing more transformed nitrogen than is used by the soil population.

The relationship between the total nitrogen content of the A_0 horizon and the changes in available nitrogen (both ammonia and nitrates) during 3 months of incubation is shown in Figure 67.

With respect to site index it is seen that with only one exception site indices of less than 16 feet are associated with a net loss of available nitrogen during incubation, while only one other sample fails to show a gain. It is to be observed that the sample with a low site index (No. 4) that produced a net gain has a relatively high nitrogen content, while the exception for the better site indices (No. 15) has a comparatively low nitrogen content.

However, there are samples from all the site index groups which

produced no appreciable gain of available nitrogen under the conditions of this experiment and the data on the nitrogen transformation of the air-dried samples of the A_0 horizon (duff) shows only a very low degree of correlation with site index except for the soils of unusually low productive capacity.

The production of nitrates is extremely variable. Only 6 of the 25 samples contained more than a trace of available nitrogen in this form at the end of the incubation period, and there was no measurable amount in any of the samples at the beginning. This is to be expected on material of this sort, although 3 samples showed a very favorable nitrate production. All 7 of the samples from high site index groups (21 feet) contained nitrates after incubation, while only 2 others showed more than a trace, both of which were unusually high in total nitrogen content.

Samples from the 2 nitrogen-transformation series were incubated with the addition of cottonseed meal to show ammonifying efficiency and with sulfate of ammonia to show nitrifying efficiency, but the results were quite variable and showed no correlation whatever with site index. Consequently they will not be presented at this time.

SUMMARY AND CONCLUSIONS

1. During 1928 and 1929 tree measurements and soil descriptions and analyses were made at more than 200 different locations in red pine plantations in Connecticut. The investigation included practically every plantation in the state that had reached an age of 12 years or more and covered as wide a range of growing conditions and as wide a geographical range as possible.

2. From the tree measurements a set of "polymorphic site index curves" based on the height growth of dominant trees was constructed with a classification age of 15 years. It was found that the height of red pine varied from a minimum of 8 feet to a maximum of 22 feet at 15 years of age, the average being 17.6 feet. In the process of making the site index curves, a method of determining site index when the exact total age of a plantation is unknown, was developed. It was called the "Three-feet-to-the-top" method. Due to the fact that most of the plantations studied were on land that was formerly used for agricultural purposes, the frequency distribution of plots among the several site index groups is much skewed, a large percentage of the plots having a fairly high site index value.

3. All the important soil groups to be found in Connecticut are included in the investigation. From a textural standpoint they varied from the coarse sand to the loam or silt loam classes.

4. The relation of various soil characteristics to the site index of red pine:

Soil series, soil texture, character of the A_0 horizon and character of the subsoil, each considered individually, can all be corre-

lated with site index, but the degree of correlation is rather low in each case.

It was impossible to discover any relation between the acidity of any horizon of the soil, as expressed by its hydrogen ion concentration, and the site index of red pine.

The total nitrogen content of the A_{1-2} horizon showed a better correlation with site index than any other factor analyzed. The total nitrogen content of the A_0 horizon was noticeably low for site indices below 10 feet but for site indices of 14 feet and more no relationship was apparent.

The moisture equivalent of the A_{1-2} horizon also exhibited a fairly high correlation with site index although less than for the total nitrogen content of the same horizon. Total nitrogen content and moisture equivalent of the A_{1-2} horizon show a better correlation with each other than either does with site index. There is some evidence, however, that the more fundamental correlation is between total nitrogen content and site index.

The silt-plus-clay content (Bouyoucos method) of the A_{1-2} horizon showed a fairly good correlation with site index for values up to 25 per cent, but above 25 per cent there was no correlation.

Colloidal content (Bouyoucos method) of the A_{1-2} horizon showed practically no correlation with site index.

There is no consistent relation between site index and the transformation of nitrogen to available nitrates and ammonia in the A_0 or A_{1-2} horizons for site indices of 16 feet or more. Low site indices were associated with low nitrogen transformation and low total nitrogen content with but one exception among 10 samples studied. Nitrate formation in the A_0 horizon occurred only on the soils with favorable site index, but several of the best soils failed to produce nitrates during 3 months incubation. Except in the cases where the total nitrogen content, and consequently nitrogen transformation, is significantly low, it seems probable that stands of the age classes included in this investigation obtain adequate amounts of available nitrogen for the maintenance of a favorable rate of growth. In most cases very little nitrate nitrogen is produced and ammonia is probably the chief source of nitrogen in the nutrition of these comparatively young red pine stands.

Correlation of the various soil factors with site index as expressed by the height increment of the dominant trees in red pine plantations was not entirely successful. This was probably due to the fact that the investigation was carried on in a region where conditions in general are favorable for tree growth and where no one of the factors that make up a site or habitat is of paramount importance.

For nearly all of the factors analyzed, a fairly high correlation was exhibited between low site index values and low values of the factor in question. Between the higher site index values and the higher values of the factors, correlation was either of low degree or entirely lacking. Apparently a low value for one soil factor is

usually associated with a low value for several other soil factors, thus creating an abnormally low value for the site as a whole, and to attribute a low site index value entirely to a low value in any one factor overemphasizes the importance of this factor. There does not seem to be a similar tendency for high values in several factors to be associated together to produce abnormally good sites.

The associated soil characteristics that usually result in a poor site are coarseness of texture in all horizons accompanied by low moisture holding capacity, a low total nitrogen content and nitrogen transformation rate in the upper horizons and the formation of a distinct layer of partially decomposed humus residues under the duff. Generally, although not always, soil having one of these characteristics will have all of them.

The complex composition of soil characteristics that make up the best sites is apparently much less definite than that which results in poor sites. The relatively small number of plots with site indices more than 2 feet above the mean site index for all plots, indicate that high values for all soil factors are seldom found on the same site, but that in a great majority of cases, soil factors that have a fairly wide range of values are associated together to form a site that is reasonably good, but not markedly higher, than the mean for all sites. Theoretically the combination of soil characteristics that should result in the best sites are fine texture, a firm to compact substratum, good water-holding capacity, a high total nitrogen content of the upper horizons, the rapid incorporation of the humus residues into the mineral soil horizon just beneath the duff, and a rate of transformation of the nitrogen into available forms that exceeds their consumption by the micro-organisms of the soil in both duff and humus-rich mineral soil.

In general, the soils of Connecticut, and probably of much of the surrounding region, may be classed as good to excellent for the production of red pine. On all but the very sandiest soils an average height increment of 1 foot or more per year may be expected for the first 30 years, provided competition caused by too close planting is relieved by thinnings.

Present Status of the Investigation

The authors realize that the stands available for this study are too young to reflect adequately the soil relationships presented here. In order to extend the present data into the future, 24 permanent sample plots, each one-fifth of an acre in size, selected from those used in this study, have been carefully surveyed and marked, and all the trees upon them measured and labelled. A complete set of soil samples from each recognizable horizon has been collected, and the chemical, mechanical, and biological characteristics of these samples are being investigated in order to compare them with conditions that will exist on these plots when the stands are more mature.

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